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THE TEST FACILITY'S ROLE IN THE EFFECTIVE DEVELOPMENT OF AEROSPACE SYSTEMS

Dr. James G. Mitchell

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AIR FORCE SYSTEMS COMMAND

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ANDREWS AIR FORCE BASE, WASHINGTON, D. C.

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FOREWORD

The study reported herein was sponsored by Headquarters, Air Force Systems Command (AFSC), Andrews AFB, Washington, D.C.; Program Element 63725F, Program Number 5599-1005. The results of the study were obtained by Dr. James G. Mitchell on sabbatical at Vanderbilt University, Nashville, Tennessee.

The research was conducted from 1 September 1970 to 1 July 1971, and the manuscript submitted for publication on 20 July 1971.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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PREFACE

This report is addressed to the technical and managerial personnel in the aerospace field who have a part in the planning and development of modern aircraft. It is particularly directed to those executives within the Air Force and Department of Defense who have within their power the controls to make changes in the aircraft development and acquisition cycle.

The investigation described in this report has been concentrated on the problems associated with environmental test facilities and their role in the development of aerospace systems. The environmental test facility is defined as ground-based (as opposed to airborne) test equipment which either duplicates or simulates natural and induced environmental parameters which are important to the test article. The test article may be a full-size flight vehicle or component, or a scaled-down version of the same. Hopefully, the measurements made on the test article in the test facility will permit prediction of vehicle or component performance which closely approximates that to be achieved in the real flight environment. Wind tunnels, turbine and rocket engine test cells, vacuum chambers, and a host of other test devices are included in this category. Although much of the philosophy expressed herein is applicable to all pre-flight aircraft evaluation facilities, this study is directed primarily toward the use and usefulness of wind tunnels in the aircraft development cycle. Except where defined otherwise, "testing" will mean wind tunnel programs.

The author performed this study for the Air Force Systems Command while on sabbatical at Vanderbilt University. However, his past experiences at the Arnold Engineering Development Center in the operation, planning and design of aerospace test facilities were most instrumental in the construction of the investigation. It has been the author's obser-

vation that many of the problems in aerospace systems development have been the result of improper use of and inadequacies in testing facilities and testing techniques. Some of the more serious problems are not subject to technical solutions, for they are the result of managerial practices and established procedures. Sometimes the cause of the problem is difficult to define, for it may be the result of a seemingly attractive management position in a related area.

The arguments and conclusions presented in the following chapters are not solely those of the author; instead, hypotheses and problems posed by the author have been evaluated by many of the experienced and knowledgeable experts who are instrumental in the development of today's aircraft. A large portion of the aircraft development projects of the past two decades have been studied in an attempt to ascertain the influence of the test facility program upon development successes and failures. The view is not that of the historian; the evaluations are by those who helped make the history. Such studies over many aircraft development projects have permitted some meaningful tests of hypotheses and the generation of a theory to optimize the use of test facilities in the aircraft development cycle.

It is not the purpose of this report to criticize individuals or organizations for their past decisions or actions. Too often an evaluation of historical data is so interpreted. It would be impossible to reconstruct the many extenuating circumstances which prompted some of the past decisions. Yet, the consequences of some of these actions can be evaluated; further, some of the situations which forced individuals into unfortunate and compromising situations can be analyzed in retrospect. The reader is asked to examine the arguments and analyses in the following chapters without trying to defend any previous decisions and activities. Instead, he is asked to review the effects of such actions as assessed by a number of distinguished experts so that he may improve his position for making future decisions.

A study of this type would not be possible without the help of many people. The author is indebted to numerous aerospace experts in the government, industry, and universities who so generously responded to the questionnaires and interviews; a list of these individuals is included as Appendix A of this report. Though not identified, the secondary contributors and coordinators played an important role in the collection of the data. The interest that so prestigious a group has shown through voluntary and detailed responses and the desire of so many to be apprised of the results of this study have been most encouraging.

A special debt of gratitude is reserved for individuals at Headquarters, Air Force Systems Command, and Headquarters, U. S. Air Force, who have provided the funds necessary to gather the data and have supported the author in many other ways. Particular mention should be made of Brig. Gen. John D. Peters, Maj. Harold Nelson, Jr., and Mr. Jerome S. Kamchi. The author also wishes to acknowledge the help of his friends and associates in the Requirements Planning Division, Directorate Plans and Technology, Headquarters, Arnold Engineering Development Center, for their assistance in searching out some of this information.

Finally, the author wishes to express his deep appreciation to the following members of the Vanderbilt University Faculty who have provided advice and consultation during this study: Dr. Edwin M. Bartee, Prof. Bruce M. Bayer, Dr. Charles E. Goshen, Dr. John W. Williamson, and Dr. Merritt A. Williamson.

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EXECUTIVE SUMMARY

The purpose of this summary is to provide a quick review of the six-chapter report on the use and usefulness of wind tunnels and related environmental test facilities in the aircraft development process. The author has tested hypotheses and explored problems by way of questionnaires and interviews; comments and judgements of 117 of the nation's leading aerospace experts are recorded in the report. This summary provides the major findings of the study, and covers the author's recommendations for corrective action and further investigation

The evaluation of the origin of the facility test plan*[1] provided the following conclusions and observations:

1. A reduction in the magnitude or quality of the facility test program is associated with an increase in technical risk in aircraft development.

2. The competitive nature of the bidding procedure for aircraft development contracts handicaps the origination and acceptance of a good facility test plan. The system acts to force test plans toward inadequacy because:

    a. The usual emphasis on low development cost and short development time encourages a potential contractor to minimize his test plan.

    b. There is a tendency to reduce attention to the test plan because of the many other items which may be considered more important in the origination and evaluation of the bid proposal.

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[1] An asterisk indicates that the phrase or word is further defined or explained in the Glossary.

c. The test plan is relatively unimportant in the evaluation of the bid or in selection of a contractor.

d. The potential contractor is sometimes hesitant to include a substantial test program in a given technical area because it may be interpreted as an indication of uncertainty on his part and work against his acceptance.

3. The test plan is primarily developed by the contractor, with some guidance by the developing organization. The Arnold Engineering Development Center (AEDC)* facility personnel have very little direct or indirect influence on the test plan. The National Aeronautics and Space Administration (NASA)* test personnel exert more influence than those at AEDC on the facility test plans for development of aircraft.

4. There is overwhelming agreement among respondents from participating agencies that some changes should be made in the method of preparing and evaluating the test plan. Many respondents recommend that more importance be attached to the test plan in the evaluation of a bid; others recommend that the test program be originated in closer coordination with ASD and AEDC and added to the contract on a cost-plus-fixed-fee basis.

5. There are indications that service funding* at AEDC is causing unfavorable working relations between AEDC and the Aeronautical Systems Division (ASD).* This is brought about by AEDC's incentive to direct test workload to its facilities and ASD's incentive to test in "free" or cheaper facilities. A result appears to be less invited participation for AEDC in establishing or advising on facility test programs.

The study of the test facility's role in implementation of the new Department of Defense (DoD)* development philosophy[2] provided the following conclusions and observations:

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[2]The new DoD development philosophy is discussed in Chapters I and IV.

1. There is strong agreement among respondents with that portion of the new DoD systems development philosophy which emphasizes demonstration of performance and reduction of risk early in the development program. The test facility is seen to have a major role in implementation of the policy and more wind tunnel testing may be required in the development cycle.

2. Many respondents do not believe that the government will change its method of operation and provide sufficient time and funds early in the development cycle to permit implementation of the new policy. Already facility testing is being de-emphasized because of greater emphasis on demonstration of performance in flight prior to a production decision. The industry designer does not believe that the government decision-maker is often aware of his dependence upon data from the test facility and his ability to assess technical risk and provide a good design based on this data.

3. The test facility can provide valuable and tangible information to the government decision-maker for his Program Decision and Ratification Decision.[3] Milestone checks of hardware performance and risk identification in test facilities are seen as a most important aspect of aircraft systems development.

4. Competitive full-scale flight prototypes* are not expected to be a part of the normal development cycle because of the costs involved; this is especially true for the large or technically advanced aircraft. Even for the less sophisticated and inexpensive aircraft, there is concern that an attempt to fund dual development programs with limited funds will result in short development schedules and little use of test facilities (e.g., the A-X).[4] The advantages of the added competition are not

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[3] Program Decision and Ratification Decision are discussed in Chapter IV.

[4] The A-X specialized close-air-support aircraft is presently under development for the Air Force.

expected to compensate for lack of design data.

5. Competitive "model fly-offs"* in the government facility during the Validation Phase[5] is an acceptable compromise between "paper studies"* and full-scale fly-offs* for many respondents. This approach provides a competitive atmosphere for development, gives the government evaluator unbiased and hard data upon which to base his judgements, yet does not incur the expense of flight prototypes.

6. The interpretation and evaluation of validation information taken from the test facility can have an influence upon substantiation of milestones and major program decisions. The existing procedures within the Air Force Systems Command (AFSC)* do not always assure the processing of the information with the requisite objectivity and freedom from biases. This situation may be expected when the evaluation and development functions are not exercised independently.

7. The government should determine compliance of the contractor's product in government facilities. These facilities should be the best available to reduce misinterpretation of the data.

8. Test personnel at government facilities should have the capacity to advise the user on the accuracy of the data that comes from the facility and give a good estimate of the correlation to be expected with flight data.

The investigation of test facility deficiencies and their consequences resulted in the following conclusions and observations:

1. The deficiencies in environmental simulation in aeronautical test facilities have had detrimental effects upon the development of aerospace systems. The major deficiencies most often mentioned by the respondents were:

   a. Lack of Reynolds number capability at transonic speeds.

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[5] The Validation Phase of systems development is discussed in Chapter IV.

b. Lack of a facility to investigate the areas of inlet-engine compatibility and nozzle-airframe integration.

c. Lack of a facility to support development of larger and more powerful subsonic and supersonic turbofan and turbojet engines.

d. Almost complete lack of good hypersonic development facilities.

2. More emphasis on testing techniques and data interpretation in existing facilities can substantially improve the contribution of these facilities to aircraft development.

3. Though not prevalent, the deficiencies in facility test capability are sometimes causing compromises in aircraft design and performance because the designer or planner is aware of the limits of the available facilities; he does not choose to propose hardware or advanced technical ideas which would either necessitate new test facilities or be developed with high risk.

4. Most respondents expect test facility deficiencies to have an even greater impact upon aircraft development during the next decade. The results of the deficiencies are anticipated to be stifled technology, more costly development programs, higher risk developments, and less than desired performance in future aircraft.

5. It is estimated that about 15% of the modern facility test program is a result of similar tests performed in different facilities in an attempt to verify data; this is because of uncertainty in the extrapolation of simulation parameters. The primary cause for duplicate testing is inadequate Reynolds number.

The following remarks resulted from a study of the role of contractor test facilities and government test facilities:

1. Most respondents believe that the aerospace contractor should have certain low-cost backyard test facilities.* Industry respondents

say that such facilities provide quick response and flexibility to the contractor, and are the key to industry research and contractor funded early development prior to government involvement. Although most government respondents acknowledge the usefulness of industry backyard facilities, many feel that "contractor owned" facilities are essentially paid for by the government as the charges and overhead are prorated over a number of aircraft development projects; they argue that the government should have better control over the number of such facilities developed indirectly with DoD funds.

2. Most respondents agree that the government should provide the high-cost test facilities as "national" test facilities for the use of everyone. However, a few respondents would prefer to see such facilities built by industry on a cooperative basis.

3. Both industry and government respondents overwhelmingly agree that contractor-owned aeronautical test facilities assist the company in obtaining government contracts. This is true whether or not the same test capability is available for the contractor's use at government facilities. Thus, a competitive situation has been created whereby the excellence of a company's test facilities has a strong influence upon its ability to capture new development contracts; this situation has resulted in proliferation of test facilities by industry.

4. Regulations and directives which force testing at certain AFSC test facilities are the subject of much concern among aerospace personnel. There are strong opinions on both sides of the argument, and the situation is promoting unfavorable working relations among both government agencies and industry. Certain accounting procedures and short-sighted incentives which are directed toward artificial economic goals are aggravating the effects of the aerospace depression and interfering with systems development.

The review of the acquisition process for AFSC test facilities resulted

in the following observations:

1. There is a lack of attention to the requirement for testing capability to support aircraft development early in the planning cycle for new weapon systems.

2. Acknowledgement of test facility deficiency prior to the Program Decision would likely reduce the probability of program approval.

3. The Military Construction Program (MCP)[6] has not been and is not expected to be an effective mechanism for acquisition of major aerospace test facilities. The requirement that need for a facility be demonstrated for an "approved" aircraft development program acts to prevent any large test facility construction.

The review of 35 aircraft development programs by aerospace experts resulted in the following conclusions and appraisals:

1. There was too often a lack of time and/or money early in the development program to permit proper use of the wind tunnel.

2. The wind tunnel test program had a strong influence on every aircraft development program evaluated.

3. A major shortcoming in many aircraft developments was insufficient facility testing early in the program (particularly prior to design freeze).

4. On three-fourths of the aircraft evaluated, the experts estimated that a more timely facility test program and better use of the more sophisticated test facilities would have resulted in:

a. Less overall development cost,

b. Superior system performance, and

c. Less flight testing required.

5. Eighty-four per cent of the aircraft experienced deficiencies in the flight evaluation which the experts believe might have been minimized

[6]The Military Construction Program is discussed in Chapter V.

or prevented with a more optimal facility test program.

Based upon the combined evaluations and opinions of the many contributing experts, a theory is developed (Chapter VI) to permit construction of an optimal wind tunnel test program for future aircraft development. A method for calculating the cost of the facility test program is included.

In order to correct some of the conditions already noted, the author makes the following recommendations:

1. The facility test plan for system development should be excluded from the competition for contracts and added to the contract on a cost-plus-fixed-fee basis. Further, the AFSC test facility personnel should be required to work more closely with the contractor and System Project Office (SPO)* in establishing the original test plan.

2. Milestones which designate specifications and minimum acceptable performance criteria should be established for the aerodynamic portion of each aircraft development program for each major decision point. All anticipated problem areas involving acceptable data limits, data correction techniques, etc., should be resolved among the contractor, SPO and test facility personnel early in the program before a conflict arises.

3. Complete facility test programs which support aircraft design should not be compromised when development procedures are modified by new ideas.

4. Competitive fly-offs of aerodynamic models in the government facilities should be given strong consideration when full-scale competitive fly-offs are not feasible.

5. The government should place increased emphasis upon evaluation of the contractors' product in government facilities; the facilities should be adequate to prevent misinterpretation of the data and argument over the results.

6. AFSC test facility personnel should possess (or develop) the

expertise to advise the contractor and SPO of the validity of the test facility data and to specify corrections to be applied to the results. They should devote more effort to correlation of facility data with flight results.

7. AFR 80-14 and/or AFSC Supplement 1 to this Regulation should be modified to provide some separation of the evaluation and development functions. Freedom for test facility personnel to test more independently and advise the SPO (and AFSC Commander, if necessary) will likely add greater objectivity to the evaluation procedures.

8. The planning function within AFSC and USAF should be revised to make consideration of the supporting test facilities an integral part of the systems planning procedure. Plans should be established as guidelines for action, with long lead-time items(like test facilities) receiving priority attention.

9. Efforts should continue through special committees and channels to fund a few major test facilities outside the MCP.

10. More permanent facility expertise should be placed in the planning function and MCP approval cycle within AFSC.

11. To prevent further undesirable proliferation of test facilities among contractors, the government should establish a policy that more clearly defines the use of government facilities in the development cycle. Such a policy must provide boundaries which limit the competition among contractors for bigger and better facilities.

12. The government must take the lead in constructing new and advanced test facilities where the need is well recognized. Such a positive action will remove the likelihood that several similar facilities will be constructed by competing industries.

13. More attention should be given to improvement in testing techniques and data interpretation in the existing facilities.

14. The costs of facility testing should be studied from an Air Force and national viewpoint. Charges for use of government facilities must either be standardized or eliminated. It is recommended that service funding

at AEDC be terminated to halt the very undesirable side effects until the issue is evaluated in a larger context.

15. The procedures given in this report for construction of an optimal facility test program are recommended as a base line for planning future wind tunnel programs.

CHAPTER I

BACKGROUND AND INTRODUCTION

There is growing concern both within the government and private industry over the unexpected increase in development costs and reduced performance of some recently developed weapon systems. The news media has diligently provided sufficient examples to excuse this author from the task of listing them. However, the problem is real and insiders in the business can probably supplement the published stories with examples of their own. None of the military services is exempt from criticism, but the Air Force has received more than its share of attention. Senator McClellan's investigation of the General Dynamics F-111 and Senator Proxmire's censure of the Lockheed C-5A program (1)[7] have brought to a focus various attempts to remedy the situation. One sometimes hears the problem stated in the press in terms of cost overrun or system performance deficiencies. Granted, these are the circumstances which cause all the attention; but elimination of these issues only cures the symptoms and does not necessarily solve the problem. As most readers realize, the real problem concerns the overall procedure for development of technically proficient aerospace systems in the most timely and economical manner.

It is not the author's intention to ignore the substantial problems associated with allocation of resources among the many proposed aerospace programs or, in a broader context, allocation of resources among the many social, civil and military needs. However, the subject to be addressed herein will necessarily be restricted to the aircraft system's development process and assumes some prior favorable decisions in the larger arena.

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[7]Numbers in parentheses refer to similarly numbered references in the List of References.

It is not surprising that accusing fingers have been pointed in many directions as some officials search for reasons for failure and others look for scapegoats. One may hear a variety of comments which place blame on poor engineering, confused contractor or government management, inadequate contract, etc. The reader can probably recall or perhaps specify other causes which prevented a particular system from fulfilling expectations, dependent upon his special interest in the system's development.

Secretary of Defense Laird addressed the problem directly on February 20, 1970, when he delivered the FY 1971 Defense Program and Budget to a joint session of the Senate Armed Services Committee and the Senate Subcommittee on Department of Defense Appropriations (2). Secretary Laird noted that as of June 30, 1969, the cost of 34 major weapon systems had grown about $16.2 billion in excess of original or baseline estimates previously reported. He stated that the largest single cause of cost growth is over-optimism in original cost estimates. An example at that time was the Air Force F-15, which had grown from an original estimate of about $6 billion to $7.3 billion within about a year. Secretary Laird admitted that both the contractors and military services have the same predispositions toward over-optimism in estimating costs. There is competition between programs for limited funds within the services, and the competition for weapon systems contracts stimulates wishful thinking among the contractors. The F-15 situation was attributed to faulty estimates in the planning stage. However, in the F-111 program the development problems were underestimated at the beginning of hardware development and the cost growth was further increased because production was started before development problems were solved. In general, there has been a tendency to cut the time and effort which should be spent in development stages because of failure to appraise adequately the risks of major failures during full-scale development. Secretary Laird identified inflation, engineering changes, system performance changes, and schedule changes as lesser reasons for cost growth.

The Deputy Secretary of Defense, David Packard, reported in an interview (3) that almost every program that is in trouble is in such a condition because development has not been done as well as it should have been, or because production was started before development was finished. Dr. John Foster, Jr., Director of Defense Research and Engineering, presented the FY 1970 Defense Research, Development, Test and Evaluation Program (RDT&E) before the House of Representatives Committee on the Armed Services on April 30, 1969 (4). In his discussion of research and development management policies, he acknowledged the same criticisms noted by Messrs. Laird and Packard. However, he reminded the committee of the circumstances which evolved to bring about this situation. Over the past 20 years several different development strategies have been tried. It was once popular to let private contractors take all the technical risks, support the development costs, and offer the government "off-the-shelf" hardware. Unfortunately, this policy did not induce the contractor to take risks to extend the state-of-art sufficiently to produce the more technically advanced systems. Another popular development scheme was "fly-before-you-buy." Several contractors carried the system development through flight demonstration at government expense and the government simply bought the best one. The prime objection to this technique was the excessively large expense for development of the modern aircraft. More recently the systems development strategy has permitted selection of a single contractor after "paper studies." The contractor is then held accountable to produce within the specified time and cost. Because costs and time schedules are based more on analyses than demonstrated performance, there has been a tendency for overruns and increased risks in attempts to meet schedules. However, the management policies and technical possibilities have not singularly shaped the development strategy, for it has been significantly influenced by national objectives and priorities. Dr. Foster pointed out that the U. S. reaction to Soviet threats, involve-

ment in armed conflicts, and variation in national goals have had significant impact on the management processes. Dr. Foster's comments serve as a reminder that the total environment has an effect on the management actions at any given time. Further, when the environment changes at a rapid pace, the management practices may be subject to criticism for their slower response.

In testimony before congressional committees Messrs. Laird and Packard and Dr. Foster have expressed a number of ideas for solution to the present dilemma. It will be noted that a total change in the development cycle is not proposed; however, it is recognized that certain procedures are not being followed and certain shifts in emphasis are recommended. Secretary Laird has noted the following steps taken to reduce cost growth:

> More realistic and accurate estimates of cost early in the program.
>
> Better risk evaluation of the uncertainties likely to be encountered in development.
>
> Emphasis on accomplishing milestones of achievement in the development phase rather than meeting a predetermined time schedule.
>
> Changes to assure a minimum committal to production before development is complete.
>
> Steps to encourage better management by both the military service and contractor, with more emphasis on meeting cost objectives rather than on meeting only scheduled and performance objectives.
>
> Allowance for inflation in estimates.
>
> Reduction of dependence on paper analysis to validate designs, with reliance on hardware demonstration and competitive prototypes where feasible. (2)

Secretary Laird notes, however, that the high costs associated with a philosophy of competitive "fly-offs" of fully-developed airframes may be prohibitive in most cases. He states also that there are general deficiencies in the amount and quality of test and evaluation before systems

are committed to full-scale development and production. The military departments have been instructed to identify and analyze the areas of high technical risk, and to defer system development until risk analysis shows that risks are acceptable for full-scale development. Deputy Secretary Packard (3) re-emphasized many of the points of Secretary Laird, particularly in relation to greater reliance on pre-production hardware development and evaluation rather than on paper studies. He contributed an additional thought when he proposed keeping the military project manager and associated military personnel on the program long enough to make a more positive contribution.

These prestigious remarks on the causes and remedies for cost overruns and system's performance deficiencies demonstrate that there is pressure to correct the situation. However, it is obvious to many that most of the steps proposed for correction do not differ substantially from the established development directives and that there would have been no problem if they had been followed in the first place. There are apparently strong counter influences and incentives that are preventing implementation of these procedures.

Instructions to "produce better cost estimates" or "provide better management" do not provide tangible directives for those trying to make a change. Nor is it clear how to implement guidelines which specify additional emphasis on problem solving early in the program in order to reduce risks. How is this to be effected within financial and time constraints? The technology must be advanced to the system stage fairly rapidly or it will be obsolete before it is developed. Where is the development system failing? Where specifically should emphasis be put? How are the rather general statements of problem solution to be implemented? In order to answer these questions, one must take a critical look at the test and evaluation program. The author asserts that it is deficiencies in this program, coupled with varying interpretations and understandings of its implementation, that present one of the more basic problems in aircraft develop-

ment.

Military research and development is evolved in a complex and confusing world; forces and counter-forces struggle for domination. The reader will recognize competition among the various technologies and approaches for any particular aircraft development; there are also competing development strategies. A conflict usually exists between the desire for technically advanced weapons systems and economic limitations. This environment is not likely to change, and to a certain extent may be considered healthy. However, there are other forces which add to this confusion. The professional men within the government who are charged with responsibility for various facets of a system's development are usually highly motivated toward job accomplishment. An examination of their working environment will show that they are sometimes put in job situations where their personal goals may not be best served by devotion to job-oriented goals and, in a larger context, where the defined job-oriented goal is in conflict with a more important total objective. Such a situation is neither healthy nor necessary.

This study attempts recognition of the many influences on the aircraft development program and on the individuals involved as it seeks to place environmental test facilities in perspective in the development strategy for aeronautical systems. The author is aware that he has isolated a small part of a complicated process for investigation; lack of recognition of other steps and emphasis in the development cycle should not be interpreted as downgrading their importance. However, the author does seek to convince the reader that inattention to the proper use of test facilities in the development cycle is causing problems with substantial detrimental effects. The reader may observe that these detrimental effects are often attributed to other causes, and the problems remain unsolved.

The author has turned to the practicing experts to test his hypotheses and gain new information. The data presented herein have been collected

primarily from questionnaires which have been completed by many of the leading people in the aerospace business. About one-half of these experts have also been interviewed by the author to assure accurate interpretation of answers and to expand key arguments. The respondents listed in Appendix A represent a substantial portion of this country's knowledge and experience in aircraft development. These individuals, both from the industry and government, have been instrumental in previous aircraft development programs and are actively making major decisions today. What they think and why they believe as they do is real and important data, whether or not one agrees with individual opinions. The reader is cautioned to look for those situations in the following discussions where honest differences of opinion are causing problems. The reader is also asked to observe areas of overwhelming agreement among the experts and (as the author has) carefully evaluate his own thoughts when they do not agree. It is not the intent of this report to tell the "true story" and straighten-out the biased reader. Instead, the author wishes the reader to gain new information which will permit him to make adjustments in his own thinking and in established procedures, and in turn to improve the aircraft development process. The knowledgeable reader will probably be able to deduct subtleties not included in the short discussions. It is hoped that these data will have usefulness far outside the bounds of this study.

Chapter II in this report is designed to give general information about the data and its adequacy. The two forms of the questionnaire are discussed, and the reader is guided through the questionnaires with comments on special objectives and terminology. The aerospace experts who completed the questionnaires and granted interviews to the author are further classified and their qualifications are noted.

Chapter III addresses the origin of the facility test plan and questions the applicability of certain incentives and Air Force Regulations. It is hypothesized that competitive procedures designed to select contractors and reduce aircraft development costs and time are causing adverse effects

on the facility test plan. An attempt is made to define the contribution of various participating groups to the test plan. Changes in the present system of originating a facility test plan are evaluated and discussed.

The role of the test facility in the systems development and acquisition cycle is explored in Chapter IV, and some shift in emphasis is suggested. It is hypothesized that the full intent of the DoD development directives is not being covered by present practices. It is further hypothesized that the test facility can and should play an increased role in the implementation of the new development policy. Very specific examples are used to show how the facility can provide milestone checks and produce information to support important program decisions.

Chapter V contains a study of the adequacy of test facilities to accomplish the desired testing and an investigation of procedures to permit improvement in facility capability. It is hypothesized that inadequacies in the test facilities are causing detrimental effects in systems development, and that this trend toward facility obsolescence is getting worse. The roles of the government and contractor test facilities are explored and evaluated in an environment which includes a declining test workload.

Chapter VI includes a historical review of 35 aircraft development programs by experts. It is hypothesized that a critical review of the use and misuse of the wind tunnel in many completed development programs will permit formulation of a theory for more optimal use of the test facility. A multiple regression analysis is used to define "predictors" which will allow characterization of an optimal wind tunnel program from basic knowledge about the proposed aircraft. Such information is considered useful as a first step in planning new test programs and should be helpful to those who attempt to predict future workloads in test facilities. The reader may be interested in the testimony of the expert evaluators which is used to evaluate the effectiveness of past wind tunnel programs.

The author has already become aware that an attempt at a scholarly

approach to such a complicated process is likely to draw criticism from those who consider themselves the real practitioners. Everyone who has been associated with any phase of the aircraft development cycle has had the opportunity to mold his own opinion based upon his unique experiences; the author is no exception. To some readers, the whole study may appear "slanted" because it does not address what they consider to be "really important" from their own experiences. Some readers may feel that "their side of an argument" is not presented in sufficient detail. The author admits brevity on both sides of most arguments; however, an attempt is made to explain minority opinion.

These analyses may fall short of confirming given hypotheses for some readers. Comparisons of historical events in aircraft development programs are not only difficult, but risky because of uncontrollable extraneous variables. Unfortunately, this task does not lend itself to a laboratory environment where parameters can be controlled at will. Further, value judgments are an essential part of the data, and value has a meaning which is personal. Conclusions based upon such qualitative diagnoses cannot be proven to an impartial observer. Under such circumstances, the closest one can hope to approach "hard data" is the thoughtful opinions of experienced and expert personnel. The author hopes that some of the comments and recommendations in this report will benefit the government decision-maker and policy-maker.

CHAPTER II

DISCUSSION OF THE RESPONDENTS AND QUESTIONNAIRES

A large portion of the information of interest in this study is composed of the observations and evaluations of knowledgeable and experienced personnel in the aerospace business. The questionnaire was selected as the most appropriate route to reach a large and diversified audience in a limited period of time; however, the author did perform some follow-up interviews with the respondents to obtain more complete information. All of the industry experts who evaluated the historical aircraft development programs were personally interviewed. The questionnaires were completed and interviews conducted during the period between early February, 1971, and mid-May, 1971. Over 50% of the questionnaires were answered and returned to the author for inclusion in this report. The responses which were received after May 15, 1971, are not included in the tabulated data, although the contributor is identified along with the others in Appendix A.

An attempt was made to survey a wide spectrum of experts from private industry and government. Of the 117 questionnaires returned, 58 are from industry and 57 from various government organizations. The author interprets such a substantial response to an admittedly lengthy questionnaire by such a prestigious group of respondents as evidence of the aerospace community's interest in some of the subjects under review. The industry respondents represent the following companies:

The Boeing Company
Fairchild Hiller/Republic Division
General Dynamics/Convair Division (San Diego and Fort Worth)
Grumman Aerospace Corporation
LTV Aerospace/Vought Aeronautics Division

Lockheed Aircraft Corporation/Georgia Company

McDonnell Aircraft Company

North American Rockwell Corporation (Los Angeles & Columbus)

Northrop Corporation

In many cases questionnaires were also returned from company corporate officers.

The government respondents represent several organizations that contribute to various aspects of the aircraft development cycle. Eighteen questionnaires were returned by personnel of the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Within this group is located the System Project Office and System Project Director (SPD); * centered here is the major responsibility for aircraft development within the Air Force. Ten questionnaires were completed by members of the Air Force Systems Command Laboratories, also located at Wright-Patterson Air Force Base; 8 respondents were from the Flight Dynamics Laboratory and 2 from the Aero Propulsion Laboratory. Four responses were received from Headquarters, Air Force Systems Command, and 3 were received from Headquarters, U. S. Air Force. These 7 responses are grouped together and will be referenced as "Headquarters." The Department of Defense Test Center is represented by the Arnold Engineering Development Center. These 13 responses are tabulated together, although 7 are from Air Force personnel and 6 are from personnel of the AEDC operating contractor, ARO, Inc. Eight questionnaires were returned by members of the National Aeronautics and Space Administration; 5 came from Langley Research Center, 2 from Ames Research Center, and 1 from Lewis Research Center. Five questionnaires were returned by members of the USAF Scientific Advisory Board, Aerospace Vehicles Panel. However, 1 of these gentlemen is with NASA and 2 are with private industry, so their responses are included in their respective groups. The other 2 board members are located in universities. These 2 responses, along with 1 questionnaire which was returned without identification, will make up the group designated as "others."

Two different questionnaire forms were used in the survey, although some of the questions are similar. Appendix B contains the shorter questionnaire which was used throughout the government and part of industry. It is an opinion-attitude survey and asks the respondent to express his beliefs and relate his experiences concerning certain procedures and practices associated with the role of the test facility in the aircraft development cycle. Appendix C contains the first 25 questions of the longer questionnaire. The remainder of this questionnaire (Questions 26 through 47) is identical with Questions 1 through 22 in Appendix B. The questionnaire of Appendix C was directed to those respondents in industry who were evaluating particular aircraft development histories.

The questionnaire of Appendix B was sent to a selected group of individuals within government and the USAF Scientific Advisory Board. The author was seeking the more experienced and senior personnel who had worked in various areas of aircraft development. The author depended upon certain respected individuals within each group to recommend others who possessed the desired qualifications. Different viewpoints were almost assured by selection of personnel from the various government organizations. Some of these shorter questionnaires were also sent to contacts in each of the participating aircraft companies, along with instructions that they were for the knowledgeable and senior personnel who would not have the opportunity to complete the longer questionnaire.

The first 9 questions in Appendix B are directed toward an investigation of the conception and development of wind tunnel test programs. Questions 10 through 14 deal with the role of the test facility as it relates to the new DoD development policy. Questions 15 through 20 and 22 are concerned with the adequacy of facilities to provide the required test environment, the effects of inadequacies, and possible remedies. Question 21 is directed toward improvement in operating procedures for DoD test facilities. As noted, these questions were on both questionnaires. The shorter questionnaire is completed with 5 questions which were general-

ized from queries on specific development programs on the longer questionnaire.

The evaluators who completed the longer questionnaire (Appendix C) were individuals who had been closely associated with the particular aircraft development program. Because the wind tunnel test program is only one of several variables which influence the success or failure of a particular aircraft development, only those individuals who were on the scene and making the history are in a position to separate the variables and distinguish among the influences. The author asked for personnel who had served in responsible positions during the development program. Most of the respondents were either Project Aerodynamicists or Engineering Managers. Sometimes aircraft were omitted from the survey because appropriate evaluators were no longer with the company. It was originally intended to have several evaulations on each aircraft, but this was possible in only a few cases. The first 12 questions of the longer questionnaire deal with historical data on the use of the test facility in the development program. Of particular interest is the quantity of testing, type of test facility, timing of the tests in the development cycle, and cost of testing. Questions 13 through 18 are an evaluation of that particular test program. The reviewers were then asked to make changes in the wind tunnel test program that would, in their opinions, have made it more effective; they were required to weigh the technical benefits of testing against the expenditure of time and money to achieve the testing. This revised test program is referred to as "optimal" in the text.

It is suggested that the reader take note of the preamble to Questions 4 and 19 in Appendix C. The former describes the type of wind tunnel tests to be included in the review. The "wind tunnel test program" includes all aero-dynamic and structural testing in wind tunnels; propulsion-aircraft integration type tests are included. Development of propulsion systems is excluded. The questionnaire differentiates between testing accomplished

in support of original development and that required by retrofit programs or follow-on versions of the same aircraft. Engine development testing was excluded from this part of the survey to limit the scope of the study, since it would have involved a different group of contractors and evaluators. The paragraph preceding Question 19 is designed to establish criteria for determination of the optimal test program. The reader is advised to read this section, for it is important to the understanding of the evaluator's objective in establishing an optimal test program.

The historical data on the facility test programs were difficult for some respondents to produce. Some companies keep this information in more retrievable form than others; some respondents had more opportunity or were more motivated to search for the data than others. There are gaps and uncertainties in the data which generally increase with the age of the aircraft development program. The cost data in particular is sketchy; in several cases it was just not available. Furthermore, the charges to a particular category varied from one company to the next. Less than 25% of the questionnaires have complete cost data which is compatible with the instructions in the questionnaire. However, the author was pleased with the overall integrity of the information, for it permitted pursuit of most of the intended analyses.

The author was particularly pleased with the narrative responses to questions on both questionnaires. Many respondents expanded their answers on added pages. The author regrets that he is unable to quote more of the excellent replies. However, for the sake of conciseness, an attempt has been made to summarize the answers and quote only the representative majority and minority opinions.

It may be noted in the cover-letters to the respondents (Appendices B and C) that the respondent is assured a degree of anonymity of his own choosing. Most of the respondents accepted the proposition offered in the cover letter; i.e., recognition as a contributor but no identification with

particular remarks or opinions. One respondent asked not to be identified, and several replied that they might be quoted. The author has honored this agreement by avoiding comments with associations which "insiders" could attribute to individual respondents.

CHAPTER III

THE ORIGIN OF THE WIND TUNNEL TEST PROGRAM

The wind tunnel test program which supports the development of a particular aircraft system is conceived and implemented in accordance with Air Force Regulation No. 80-14 and AFSC Supplement 1 to that regulation (5 and 6). It is assumed that most readers are familiar with these documents; for those who are not, a few words of explanation should suffice for this discussion. The scope of the referenced documents is broader than just the facility test program, and encompasses all testing (including flight testing) for all phases of the test program, thus covering the life cycle of the system from its beginning through the acquisition phase. However, the interest in this study is in that portion of the documents which is connected with development and implementation of the facility test plan.

The responsible development organization (usually ASD), acting through the System Project Office, is directed via the regulations to provide for the development of the System Test Plan. The individual test organizations within the AFSC are directed to provide certain advice and support to the developing organization to the extent requested by the developing organization. It is standard practice for a potential contractor (bidder) to submit a rather detailed test plan for wind tunnel testing as part of his response to the invitation to bid and in accordance with guidelines in the invitation. The bidder's test plan is thus evaluated along with the remainder of his proposal and exerts some influence upon the acceptance of that proposal.

In this chapter, the adequacy of the established procedure for origination of the wind tunnel test plan is questioned. It is hypothesized that conflicting incentives tend to reduce the scope and effectiveness of the test plan. An investigation is made to determine the influence on the test

plan by certain parties within the government who are in positions to make a contribution. Finally, some alternatives for changes inthe existing procedures are suggested and evaluated.

There are no "right" or "wrong" replies to these questions, for they only indicate the respondent's belief in the truth of the proposition. As several respondents have observed, a definite answer would require reference to a particular example; otherwise, there will always be exceptions. The author had recognized this situation and the respondent was instructed to base his answers on his overall experience and observations. The strength of his agreement or disagreement should then be some measure of the validity of the hypothesis.

Factors that Influence the Facility Test Plan

It is speculated that the emphasis on low development cost and a short time period to produce a flight aircraft has the effect of encouraging the prospective contractor to reduce the scope of his proposed test program and thus increase his risks. Few will deny that such emphasis is indeed a factor in most development programs. The military developing agency has usually specified a date for aircraft operation which dictates a rather hurried development program, and the prospective contractor is keenly aware that development funds are limited.

In order to agree with this hypothesis, the respondent must acknowledge that both the pressures of time and cost act to force the contractor to reduce his proposed facility test plan. Further, the respondent must agree that reduction in facility test programs is associated with increased technical risk. This premise is addressed in Question 1, Appendix B, and the results of the survey are noted in Table 1. It is clear that most of the experts agree with the hypothesis with 87% agreeing and 10% disagreeing. Thirty-one percent were motivated to agree strongly. The conclusion to be drawn from this response is that about 9 out of 10 of the people surveyed

acknowledge that pressures associated with development cost and time do exist and force one in the direction of less testing; further, a reduced test facility program is associated with increased technical risk.

TABLE 1

REPLIES TO HYPOTHESIS THAT EMPHASIS ON LOW DEVELOPMENT COST AND SHORT DEVELOPMENT TIME ENCOURAGES THE BIDDER TO REDUCE THE SCOPE OF THE FACILITY TEST PROGRAM AND INCREASE HIS RISKS

Agency	Disagree Strongly	Disagree	No Opinion	Agree	Agree Strongly
Industry	1	8	1	34	14
ASD	0	3	1	10	4
Headquarters	0	0	0	4	3
AFSC Labs	0	0	1	7	2
AEDC	0	0	0	3	10
NASA	0	0	0	5	3
Other	0	0	0	3	0
Totals	1	11	3	66	36

It is suggested that the developing agency and/or bidder have a tendency to minimize attention to the test plan in the bid proposal because of the many other items they may consider more important. For example, emphasis on aircraft performance, cost proposals, development schedules, etc. may not permit the bidder or evaluator to direct much attention to the adequacy of the test plan at this point in time. This supposition is addressed in Question 2, Appendix B, and the response is summarized in Table 2. The hypothesis is affirmed by a small majority, with about 55% in agreement and 39% opposed. However, some stratification of opinion among the different groups might be noted here. The industry personnel reject the hypothesis by about the same ratio that the total group accepts it. Many of the industry respondents are responsible for development of

the test plan within their respective companies. The AEDC and NASA respondents, who are test oriented, are very much in agreement with the hypothesis (86% agreement).

TABLE 2

REPLIES TO HYPOTHESIS THAT A TENDENCY EXISTS TO MINIMIZE ATTENTION TO THE TEST PLAN BECAUSE OF THE MANY OTHER ISSUES CONSIDERED MORE IMPORTANT IN THE BID PROPOSAL

Agency	Disagree Strongly	Disagree	No Opinion	Agree	Agree Strongly
Industry	3	29	2	23	1
ASD	1	6	3	7	1
Headquarters	0	1	0	3	3
AFSC Labs	0	3	1	6	0
AEDC	0	1	0	6	6
NASA	0	1	1	6	0
Other	0	1	0	2	0
Totals	4	42	7	53	11

It is speculated that many of the personnel involved in the preparation and evaluation of the bid may feel that the test plan in the potential contractor's proposal has little influence on the evaluation of the bid and thus has little effect upon selection of the contractor. Question 3, Appendix B, is directed to an evaluation of this premise and the results are listed in Table 3. Overall, the hypothesis is accepted; 46% affirm and 33% reject. Evidently, there is substantial belief on both the part of the industry bidder and government evaluator that the facility test plan in the proposal carries little weight--at least more often than not.

The replies to these first three questions lead one to believe that the competitive nature of the bidding procedure hinders rather than helps the goal of achieving a good facility test plan. One might conclude that

the system acts to force test plans toward inadequacy because:

-- They are not really important in deciding who gets a contract.

-- Time and effort spent in preparing and evaluating the contract is better directed to more important issues.

-- The usual emphasis on low development cost and short development time encourages a potential contractor to accept increased risks through minimization of his test plan.

TABLE 3

REPLIES TO HYPOTHESIS THAT THE MAGNITUDE AND QUALITY OF THE TEST PLAN IN THE BID PROPOSAL HAS LITTLE INFLUENCE ON THE EVALUATION OF THE BID AND SELECTION OF THE CONTRACTOR

Agency	Disagree Strongly	Disagree	No Opinion	Agree	Agree Strongly
Industry	0	19	16	20	3
ASD	1	7	2	6	2
Headquarters	0	2	1	3	1
AFSC Labs	2	0	2	5	1
AEDC	1	1	0	8	3
NASA	1	4	3	0	0
Other	0	1	1	1	0
Totals	5	34	25	43	10

The interpretation of these questions and answers was substantiated in the personal interviews. Another interesting point was acknowledged by several individuals in the interviews. Because of the stress on low risk development programs, the contractor tries to propose the best system performance with fewest unproven technical advances. He may feel that proposing a substantial facility test program for any one technical area will indicate his uncertainty in that technical area and will work against acceptance of his proposal.

Thus, it appears that the incentives introduced in the process for selection of a contractor are resulting in acceptance of increased risk before the development program even begins. It is to be expected that the individuals involved in the preparation and evaluation of the proposal will direct their attention to those items that they feel are most influential in determining the winner of the contract. It has been demonstrated that this emphasis has a natural side effect; i.e., less attention to the origination of the facility test plan. The far-reaching consequences of an inadequate test program are discussed in later chapters. However, it is important to note here that the incentive system as applied to test plan origination is achieving exactly opposite results from those desired; i.e., increased risks and the possibility of overall increased development costs.

Contributors to the Test Plan

There are several parties who are associated with the origination of the test plan. It is the intent of the following analysis to determine the degree of influence various groups have on the magnitude and quality of the facility test plan. The military developing organization (ASD) is responsible for the development of the test plan by regulation; however, it may seek help and advice from other government agencies. It is of interest here to measure just how much influence each party exerts on the facility test plan by his own estimate and that of others.

It is speculated that the contractor is the most influential figure in the development of the facility test plan. It is he who prepares the test plan as part of his bid proposal. This hypothesis is addressed in Question 4, Appendix B, and the replies are noted in Table 4.

TABLE 4

REPLIES TO HYPOTHESIS THAT THE CONTRACTOR DOES MOST OF THE WORK IN PREPARING THE FACILITY TEST PLAN FOR SYSTEMS' DEVELOPMENT

Agency	Disagree Strongly	Disagree	No Opinion	Agree	Agree Strongly
Industry	0	4	1	44	9
ASD	0	3	1	13	1
Headquarters	0	1	2	3	1
AFSC Labs	0	0	0	9	1
AEDC	0	0	1	6	6
NASA	0	0	2	6	0
Other	0	0	1	2	0
Totals	0	8	8	83	18

The hypothesis is strongly accepted; 86% agree and 7% disagree. Evidently, the contractor is a very important figure in the development of the test plan.

Since the contractor plays such an important role in origination of the test plan, it is desirable to see how much influence the responsible organization (ASD) exerts on the size and quality of the test plan. Question 5, Appendix B, is worded to suggest little influence, and the results are tabulated in Table 5. Overall, the hypothesis is rejected with 56% disagreeing and 36% agreeing. However, if the ASD responses are removed from consideration, the proposition is rejected by only a 50%-42% margin. It would appear that other respondents do not agree with the developing organization on the extent of influence exerted, since ASD rejected the hypothesis by a ratio of 95% to 5%.

TABLE 5

REPLIES TO HYPOTHESIS THAT THE MILITARY DEVELOPING AGENCY EXERTS VERY LITTLE INFLUENCE ON THE MAGNITUDE OR QUALITY OF THE TEST PLAN

Agency	Disagree Strongly	Disagree	No Opinion	Agree	Agree Strongly
Industry	0	33	4	18	3
ASD	2	15	0	1	0
Headquarters	1	3	0	2	1
AFSC Labs	1	3	1	5	0
AEDC	0	3	1	6	3
NASA	0	3	3	2	0
Other	0	2	0	1	0
Totals	4	62	9	35	7

The DoD facility test personnel (primarily AEDC) also participate in the origination of the facility test plan; however, their participation is controlled to a large extent by invitation from ASD. The extent of AEDC's influence on the magnitude and quality of the facility test plan is explored in Question 6, Appendix B, and the responses are shown in Table 6. Sixty-one per cent accept the hypothesis and 25% reject it. Several responses to Questions 6 and 7 had split answers; e.g., agree in magnitude, disagree in quality. These few partial agreements were tabulated as disagreements, but do not change the trend of the results. The AEDC respondents agree (12 out of 13) that they exert little influence on the test plan. Thus, it would appear that the facility test personnel within the Department of Defense are not contributing significantly to the development of the facility test plan.

TABLE 6

REPLIES TO HYPOTHESIS THAT DoD TEST FACILITY PERSONNEL EXERT VERY LITTLE INFLUENCE ON THE MAGNITUDE AND QUALITY OF THE FACILITY TEST PLAN

Agency	Disagree Strongly	Disagree	No Opinion	Agree	Agree Strongly
Industry	0	15	7	30	6
ASD	0	7	3	8	0
Headquarters	0	2	1	3	1
AFSC Labs	0	2	1	7	0
AEDC	0	1	0	10	2
NASA	0	1	5	2	0
Other	0	1	0	2	0
Totals	0	29	17	62	9

Almost all military aircraft developments experience some testing in the NASA test facilities. Although one would not expect NASA's participation to be covered in Air Force Regulations as is that of the DoD test facilities, it is likely that they exert some direct or indirect influence on the test plan. Question 7, Appendix B, is addressed to this premise, and the results are noted in Table 7. The hypothesis is accepted by 46% of the respondents and rejected by 40%. Comparison of these results with those of Table 6 leads one to the conclusion that NASA test personnel exert more influence than do the DoD test personnel on the facility test plans for development of aircraft.

It should be noted that these results are not necessarily limited to the Air Force systems. It is quite possible that some contractor and NASA respondents have also worked on Navy aircraft development programs and have included these experiences in their responses. The study would be more complete if Navy test personnel, laboratories and development organizations had been surveyed, but it was necessary to limit the scope of the

study. However, interviews with respondents indicated that their responses were primarily directed toward the Air Force Systems Command, ASD (as the developing organization), and AEDC (as the DoD test center).

TABLE 7

REPLIES TO HYPOTHESIS THAT NASA TEST FACILITY PERSONNEL EXERT VERY LITTLE INFLUENCE ON THE MAGNITUDE AND QUALITY OF THE FACILITY TEST PLAN

Agency	Disagree Strongly	Disagree	No Opinion	Agree	Agree Strongly
Industry	3	23	6	24	2
ASD	0	5	2	10	1
Headquarters	1	0	1	4	1
AFSC Labs	0	4	4	2	0
AEDC	1	5	1	6	0
NASA	2	2	1	2	1
Other	0	1	1	1	0
Totals	7	40	16	49	5

A New Procedure

It is appropriate to ask if the respondent is satisfied with the present method of test plan origination or if he would prefer some reorientation of emphasis or procedure to change the existing method of preparing and evaluating the test plan. Question 8 seeks to determine if some reorientation might be expected to improve the present system; the results are shown in Table 8. There are 84% affirmative answers and 12% negative. Obviously there is a very strong belief that some changes in test plan origination are desirable and can be beneficial.

TABLE 8

RESPONDENT'S EXPECTATION THAT REORIENTATION OF EMPHASIS OR PROCEDURE WOULD IMPROVE THE EXISTING METHOD OF PREPARING AND EVALUATING THE FACILITY TEST PLAN

Agency	No	Yes	No Answer
Industry	9	45	4
ASD	3	14	1
Headquarters	0	7	0
AFSC Labs	2	8	0
AEDC	0	13	0
NASA	0	8	0
Other	0	3	0
Totals	14	98	5

The possibilities for changes in the system are numerous; however, it is desirable to gain some knowledge of the experts' preferred direction of change. In Question 9, four different shifts in emphasis and/or procedure are suggested for the consideration of the respondent; he is asked to compare each choice with every other choice and indicate his preference. The sum of these preferences is indicative of the popularity of the choice. The four choices are repeated here for the reader's convenience.

a. Continue existing procedures, but have the military developing agency attach less importance to the test plan in the evaluation of the bid.

b. Continue existing procedures, but have the military developing agency attach more importance to the test plan in the evaluation of the bid.

c. Have the company bid the test plan only as a lump-sum expenditure and evolve the details if and when it gets the contract.

d. Omit the test plan from the bid proposal. Develop the test plan after contract award with the combined efforts of the selected contractor,

Systems Project Office, and government test facility personnel. Add to the contract on a cost-plus-fixed-fee basis.

The results are noted in Table 9. The numbers in parentheses show number of "first choices" for that particular suggested change.

TABLE 9

RESPONDENTS' CHOICES FOR CHANGES IN THE METHOD OF FACILITY TEST PLAN ORIGINATION

Agency	a	b	c	d
Industry	50 (1)	80 (19)	53 (6)	82 (19)
ASD	16 (1)	37 (10)	17 (1)	20 (4)
Headquarters	4 (0)	13 (3)	12 (2)	16 (4)
AFSC Labs	5 (0)	19 (5)	9 (0)	15 (3)
AEDC	2 (0)	24 (3)	9 (0)	26 (8)
NASA	4 (0)	20 (6)	7 (0)	16 (2)
Other	3 (0)	8 (2)	1 (0)	5 (1)
Totals	84 (2)	201 (48)	108 (9)	180 (41)

Not all respondents who answered "yes" to Question Number 8 made selections from the suggested options. Others had ties for "first choice," thus resulting in an indicated 100 first choices; 48% prefer option "b" and 41% prefer option "d." Industry split about evenly between the two options. The AEDC respondents were 8 to 3 in favor of option "d" over "b," presumably because it permits greater participation on their part in preparation of the test plan.

As might be expected, several alternative plans were suggested by the respondents (even by some of those who ranked the indicated choices). In the interviews it became apparent that a good many respondents felt that they were forced to option "b" because of limited choices and disagreement with some part of the other options. Many respondents did not want the test plan completely omitted from the bid proposal, as suggested by option "d." Yet, they could see no need to include a detailed test plan

and agreed that the test plan should be funded on a "cost-plus" basis. Most of the industry respondents who were interviewed liked the idea of developing the final test plan in closer concert with ASD and AEDC. It was suggested that NASA personnel should also be included if they are to contribute to the test program. These respondents indicated that such a plan would tend to promote harmony among all parties and focus attention to make the resulting test program more successful.

One of the objections to a plan which omits the detailed test plan from the bid proposal is the added time interval after contract award needed to finalize a facility test plan. However, most respondents agreed that all involved parties should have already completed their "homework" and that agreement among the participants should take from one to three weeks (depending upon the magnitude of the test program). Under such a plan, it is intended that the contractor put at least as much preparation into his test plan as he now does; however, the participating government organizations would be expected to increase their present involvement in definition of the test plan.

The interviews and questionnaire responses gave evidence that there is some disagreement between AEDC and ASD personnel as to the desirable degree of AEDC participation in definition of the test plan. The reader will recall that by regulation AEDC primarily responds to requests from ASD. The results of Question 6 (Table 6) indicate that AEDC personnel are presently contributing little to test program planning. It was noted in the discussion of Table 9 that AEDC prefers the option that permits more participation on their part. It may also be observed that ASD rejected this option very strongly. From the interviews and comments on the questionnaires, the author has concluded that service funding* at AEDC is largely responsible for the apparent conflict. It will suffice for the unfamiliar reader to know that this is a funding procedure whereby AEDC operates with a working capital fund, from which operating expenses are paid, and which is

reimbursed through charges to benefiting organizations. Thus, ASD is required to spend its development funds for testing at AEDC, and AEDC is dependent upon its workload for its continued operation. Add to this the fact that NASA is permitted to perform testing free for ASD and one can readily see the basis for suspicion of motives. AEDC is given an incentive to direct a large portion of the test load to their own test facilities; ASD is given an incentive to direct work away from AEDC so that its development funds can be spent for other purposes.

The author is not critical of either the organizations or personnel; everyone appears to be reacting in a normal manner to the incentives presented to him. However, service funding has evidently contributed to tensions and suspicion of motives among Air Force organizations that should be working in close harmony. The evidence collected in this study shows service funding at AEDC to have a very negative influence on the magnitude and quality of the facility test program for aerospace systems development.

Recommendations

1. The evidence gathered in this study indicates that the facility testing program is compromised at its inception by the incentives introduced in the competition for aerospace development contracts. Because the test program is an easily identified entity and because the reduction or elimination of parts of the test program incur a risk that is not easily measured or defined, it is likely that the facility test program will continue to be adjusted unduly to accommodate time and cost objectives under the existing system.

RECOMMENDATION: The facility test plan for aerospace systems development should not be a part of the competition for development contracts, but should be added to the contract of the selected contractor on a cost-plus-fixed-fee basis.

2. The testimony from the interviews and questionnaires indicates that some government personnel are not making their maximum contribution to the facility test plan for systems development. In particular, it was demonstrated that the AFSC test facility personnel exert little influence on the test plan. Many of the experienced respondents believe that the test program could be improved if all contributors had the opportunity for input and coordination at the time of test plan origination.
RECOMMENDATION: <u>AFR 80-14 (and/or AFSC Supplements) should be modified to require more participation and coordination by the involved government agencies in development of the facility test plan. The involvement of the AFSC test facility personnel should be standard procedure; i.e., not so dependent upon requests from the developing agency</u>.

3. There is reason to believe that service funding at AEDC is producing incentives which are hindering coordination among government agencies and which are reducing the effectiveness of the facility test program.
RECOMMENDATION: <u>Service funding at test centers should be subjected to a critical review at AFSC and USAF. Detrimental effects of this procedure should be carefully weighed against the claimed benefits</u>. (This subject is further discussed in a later chapter.)

CHAPTER IV

EMPHASIS IN THE SYSTEMS DEVELOPMENT CYCLE

The concerns of the officials of the Department of Defense and their recommended changes in the military system development and acquisition cycle were mentioned in Chapter I. On May 28, 1970, Deputy Secretary of Defense Packard sent a memorandum to the DoD hierarchy and military departments in which he outlined broad policy guidance for the acquisition and development of major weapon systems (7). In this memorandum, the Deputy Secretary covered management, development (conceptual and full-scale), production, and contracts. It was intended that the broad policy guidance be translated into appropriate action by all the Military Services.

The memorandum has drawn widespread acclaim from most of those affected and the proposed shift in development policy has been praised in many of the publications of the aerospace industry. Dr. Karl Harr, Jr., president of the Aerospace Industries Association, saw the memo as "one of the most potentially constructive documents generated within the Pentagon in years" (8). All respondents to the questionnaires had heard of the new policy and were aware that some changes in the aerospace development and acquisition cycle were expected. However, there were some differences in interpretation regarding the proposed changes, perhaps because the policy guidance is so inclusive.

Some elements of the new policy guidance are not so elusive and are being implemented. In the past, certain aircraft development programs have deliberately introduced tooling for production--and sometimes initiated production--before it was demonstrated that the aircraft would perform satisfactorily (e.g., the F-111). The policy guidance made it very clear that

this was one procedure that should be corrected, for changes in tooling are costly and modifications to unsatisfactory aircraft are usually even more costly. Corrective action was clear; one should fly the aircraft and demonstrate its performance before making a production decision. The penalty is a longer development cycle; the benefits are obvious. Some of the other changes directed by the Deputy Secretary regarding type of development contracts and certain management practices have also been interpreted and implemented to some degree. However, the author has observed that procedures proposed for implementation of the directives do not appear to fully recognize the possibilities for "risk identification and reduction, evaluation of technical achievements and demonstration of performance" prior to flight of the aircraft. Yet the policy guidance is worded so that it seems undeniable that such emphasis is expected.

The hypotheses to be addressed in this chapter are centered around the proposition that risk identification and reduction, technical evaluation and hardware demonstration are important in the aircraft development cycle prior to flight of the aircraft; it is suggested that these functions are not receiving sufficient attention and emphasis. The role of the test facility in support of this proposition is explored in different settings; first in relation to the new DoD development policy, and then as a contributor to the management decision-making process. It is then hypothesized that existing procedures for processing information for the development decisions are not entirely adequate. As before, the author has turned to the practicing aerospace experts to test the hypotheses and to solicit their advice regarding the proper role of the test facility. Those who are not familiar with the function of the test facility in support of system development are directed to a thesis by Col. Joseph Henry at the Air War College (9). Col. Henry has presented a convincing argument for use of test facilities in implementation of parts of the new development philosophy, and has illustrated his position with historical examples drawn primarily from

propulsion system development.

The reader should be aware that the term "wind tunnel testing," although widely used in industry, is usually a misnomer. "Testing" implies that one is seeking to determine whether or not a design is adequate, whereas most wind tunnel "tests" are conducted to gather basic design data, either to evolve an adequate configuration or to gather definitive design data on a configuration previously determined to be satisfactory. Hence, most wind tunnel "tests" are not tests at all, but are aerodynamic simulation studies (10). This differentiation in test emphasis may be observed in the later discussions.

Agreement with the New Development Philosophy

It is first desirable to determine the strength of agreement of the aerospace experts with portions of the philosophy of systems development as interpreted by the author. Question 10, Appendix B, is designed to ascertain the respondents' agreement with emphasis on risk reduction, technical evaluation, correction of mistakes and appropriate trade-offs early in the development cycle before completion of the flight vehicle. (The reader may wish to review the preamble to Questions 10-14 in Appendix B so that he will have a better feeling for the intent of the author and respondents.) The results of this question are shown in Table 10. There is obviously overwhelming acceptance of the new policy and pre-flight emphasis; however, from the respondents' comments on the questionnaires and in the interviews, it was evident that a few respondents who answered in the affirmative did not agree with the proposition as posed by the author, but instead have agreed with other portions of the policy as they have chosen to interpret them. Also, there were many qualified agreements and reservations explained in the comments to this question. In the following paragraphs, the author will attempt to group some of these comments and explain the various positions.

TABLE 10

RESPONDENTS' AGREEMENT WITH EMPHASIS IN THE NEW DEVELOPMENT PHILOSOPHY ON PRE-FLIGHT EVALUATION DEMONSTRATION AND RISK REDUCTION

Agency	Strongly Disagree	Disagree	No Opinion	Agree	Agree Strongly
Industry	0	3	2	35	18
ASD	0	0	0	9	9
Headquarters	0	0	0	3	4
AFSC Lab	0	1	0	4	5
AEDC	0	0	0	5	8
NASA	0	0	0	2	6
Other	0	0	0	3	0
Totals	0	4	2	61	50

Most respondents interpret the new philosophy as a peace-time development approach, where cost savings are more important than development time. This "step-by-step" development cycle is expected to assure (within reason) that problems have been solved before more substantial investment is made in the advanced stages of development. This is opposed to the war-time philosophy, where it is necessary to take chances with concurrent development efforts just to get the new system into the national arsenal at an early date. Most respondents agree that the new emphasis in development will likely extend development time; however, only a few see this as having a detrimental effect. Most respondents expect overall development costs to decrease. Only a few of the respondents are making a direct association between the expenditure of time and money. Such an association was certainly accurate for the accelerated concurrency approach, where any delay in the development program has usually been very expensive because of continuing but unproductive concurrent phases. However, most respondents expect the new development cycle to account for adequate time in each step of development,

with build-up in the next phase curtailed until the appropriate time.

There are some notes of caution which practitioners of the new policy might well observe. Some respondents fear that the philosophy may not permit rapid response to a threat from a potential enemy. The author does not share this concern; if the technology base is maintained, it should be relatively easy to accelerate the development cycle to meet a threat. A more important consideration may be the hesitancy to undertake a high-risk development project which offers a very good payoff. Also, some respondents caution that a program can be drawn out time-wise to the point where it loses its glamour and its support withers; e.g., the Supersonic Transport (SST) and DYNASOAR.

Several respondents indicated agreement with the policy, but suggest that its applicability depends upon the nature of the system being developed; i.e., conventional or advanced. They argue that the policy implementation would improve a development program with a great deal of advanced technology, but would only hinder a more conventional development by stretch-out. A few suggest that only certain elements of the system be included in this concept (the airframe, propulsion system, flight controls and fly-away components), with other elements developed via a different approach (avionics, fire control, etc.).

Most respondents support the new policy without qualification. They say that implementation of this policy will result in better systems and eliminate bad systems at less cost. They believe that it can be accomplished just as quickly and more cheaply if the development program is planned this way from the beginning and executed according to plan. It is argued that it is far easier and less costly to determine and correct deficiencies early in the development program rather than to engage in modifications to flight vehicles--even the initial prototype flight vehicle.

Many of the respondents who readily accept the new development policy and emphasis have revealed a great deal of skepticism that it will

be implemented. The argument here does not address prototype flight demonstration prior to a production decision; all respondents seem to agree that this is desirable and will be practiced because the implementation is so obvious. Instead, the skepticism centers around recognition and practice of techniques to gather design data, reduce risk, and demonstrate performance prior to vehicle flight. Two of the comments from respected members of industry sum the contractors' majority viewpoint very well:

> "Until the government is willing to honestly face the early cost impact of doing business this way, and is willing to give an honest contractor credit in his proposal for recognizing and addressing this problem cost-wise, there is little likelihood for improvement."
>
> "The theory is excellent; but in the real world with limited development funds, even this approach tends to de-emphasize the importance of testing; e.g., the B-1 development program."[8]

Test Facility Role in the New Policy

It was demonstrated in the preceding discussion that the proposed emphasis on pre-flight aircraft development was accepted by almost all the aerospace experts. In this section of the report, the role of the test facility in implementation of this policy emphasis will be examined. It is hypothesized that the shift in emphasis in the development cycle will permit the test facility to be more useful and influence the system development more strongly. This proposition was posed in Question 11, Appendix B, and the results are shown in Table 11.

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[8]The B-1 Advanced Strategic Bomber is being developed by the North American Rockwell Corporation.

TABLE 11

REPLIES TO HYPOTHESIS THAT THE SHIFT IN EMPHASIS IN THE DEVELOPMENT CYCLE WILL PERMIT THE TEST FACILITY TO BE MORE USEFUL AND INFLUENTIAL IN SYSTEMS' DEVELOPMENT

Agency	Strongly Disagree	Disagree	No Opinion	Agree	Agree Strongly
Industry	1	10	3	37	7
ASD	0	2	2	13	1
Headquarters	0	0	1	4	2
AFSC Labs	0	0	0	8	2
AEDC	2	0	2	5	4
NASA	0	1	0	5	2
Other	0	1	0	2	0
Totals	3	14	8	74	18

Although these results substantiate the hypothesis by a large majority (79% agree, 14% disagree), they do not fully indicate the support given the hypothesis. The wording of the question made the answer uncertain for the respondent who was skeptical about implementation of the policy. Many of the respondents reworded the question before answering to indicate that the test facility "could" or "should" be more useful; however, they were reluctant to state that it "would" be. Over one-half of those who disagree or disagree strongly with the hypothesis, stated in their comments that their disagreement was based on the same interpretation. Actually, only about 5% of the respondents disagree with the proposition intended in the question. These 5% appear to believe that the prototype aircraft should be built and put into the air as quickly as possible. They see the test facility in the primary role of complementing flight evaluation and correcting deficiencies found in flight. Following are some of the comments which seem to best represent the attitude of the 95%. These comments have been selected from those in industry who use the data to design aircraft. The reader will observe in these comments a confidence in the use

of the test facility, a belief that the policy could be implemented, but a reluctance to believe that it will.

> "Technical risk can be assessed prior to flight--very accurately. The Military Developing Agency schedules do not allow configuration development and final production version verification through wind tunnels, simulator and static test to occur prior to design and tooling go-ahead. If it did, untold billions ($) in cost would be saved--at a cost of about a year in the development schedule."

> "By now we should be able to develop in ground-based facilities (wind tunnel/simulators) an aircraft configuration without flying the hardware."

> "The new policy will tend to further compress test facility time. Management will feel that risk is less; i.e., they will feel that they can 'fix it in flight.' Too few decision-makers understand that relatively risk-free preflight configuration development is possible."

> "The policy is being interpreted to place more emphasis on the flight vehicle. This will tend to shorten the preflight development cycle; thus, test results will not get into the design and risk will be increased."

> "The time scale for development testing in facilities is compressed. There may be even more reliance on flight testing than in the past."

As a complement to the hypothesis of Question 11 (Table 11), it is desirable to determine how the aerospace experts expect the magnitude of facility testing to be influenced by the shift in development emphasis. The respondent is asked in Question 12, Appendix B, if this new development philosophy will require more or less facility testing; the results are shown in Table 12.

Obviously, the respondents do not expect the output of the test facility to be reduced as a result of the new policy. Most of the respondents interpreted the question as it was intended, i.e., more or less testing on each individual development project. At least two of those who responded "less" did so because they expect fewer system development programs and

and therefore less overall facility testing. Another two of the six who replied "less" expect less testing on each development project in the long-run because of decreased testing in the facility to correct deficiencies discovered in flight. At least one respondent believes that there will be more testing because there will be more time for testing and people will find things to test. As in the preceding question, several respondents reworded the question to read "should require" rather than "will require."

TABLE 12

RESPONDENTS' ESTIMATES OF THE EFFECT OF THE NEW DEVELOPMENT POLICY ON TEST FACILITY WORKLOAD

Agency	Less	No Change	More	No Answer
Industry	3	23	29	3
ASD	0	7	11	0
Headquarters	0	1	5	1
AFSC Labs	1	3	6	0
AEDC	1	2	10	0
NASA	1	3	3	1
Other	0	1	1	1
	6	40	65	6

The responses shown in Tables 11 and 12 clearly demonstrate the respondents' belief that the test facility can and should play a more influential role in aerospace systems development; implementation of this philosophy is expected to increase the use of the test facility in support of each system development program.

Confirmation Testing in the Facility

DoD has adjusted functional responsibilities for acquiring major weapon systems so that decision points arise at the beginning of several critical phases (3). Figure 1 shows an abbreviated development cycle with the three decision points introduced. Note that the decisions are reserved for

FIGURE 1

FUNCTIONAL RESPONSIBILITIES FOR WEAPON SYSTEMS ACQUISITION

Primary Responsibility	Conceptual Phase	Program Decision	Validation Phase	Ratification Decision	Full-Scale Development	Production Decision	Production	Deployment
Military Service	X		X		X		X	X
DoD		X		X		X		

DoD and that two of the three decisions must be made prior to full-scale development. Although the Validation Phase may include a prototype flight vehicle (or even competitive prototypes), the more usual case will be first flight in the Full-Scale Development Phase. The high costs associated with prototype development will usually prevent such a philosophy from being pursued in the Validation Phase on both advanced design and large, expensive aircraft. Since the emphasis in the policy guidance is on demonstration of performance and progress with hardware and reduction of reliance on paper studies, it is suggested that the test facility can provide information at these decision points of benefit to the decision-maker. In the interim between paper studies and flight demonstrations, the author is unaware of any other instruments to measure technical progress except test facilities, flight simulators, etc. This proposition is addressed in Question 13, Appendix B, and the respondent is asked what contributions the facility might make in an evaluation role at these major decision points prior to aircraft flight. The intent is to define the type of hardware demonstrations and milestone checks in each phase that will provide the confidence needed by the decision-maker. Some of the statements made by the respondents are quoted in Exhibits 1 and 2, Appendix D. Although both the Conceptual Phase and Validation Phase are briefly described in Question 13, some supplementary comments seem appropriate prior to a discussion of the respondents' replies. The reader should be aware that the objective here is not to cover the complete scope of each development phase, but only that portion which might be supported by technical data from test facilities.

The Conceptual Phase has as its objective the definition and selection of systems which warrant further development.[9] Economic, political and

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[9]The descriptive comments on the Conceptual and Validation Phases are taken from a Draft Interim AFSC Pamphlet entitled, "Systems Management, Guide for Management on the Systems Acquisition Life Cycle."

technical trade-offs are performed and tested against military need. Technical uncertainties are supposed to be identified in the Conceptual Phase for resolution during the Validation Phase. However, it is likely that some minimum state-of-the art demonstration will be required for key subsystems and components. Preliminary designs are evaluated from the standpoint of feasibility and technical risk. In the first part of Question 13, the respondents are asked to indicate the kind of information which decision-makers should have available from the test facility to support their Program Decision. Some of the representative comments are quoted in Exhibit 1, Appendix D.

The Validation Phase has as its objective the establishment of firm and realistic performance specifications which meet operational requirements. Major program characteristics (cost, schedule, and technical) are validated and refined through extensive study, analysis, hardware development and sometimes prototype testing. This Phase should provide high confidence that risks have been resolved (or minimized) and that the probability of successful development is great. The decision-maker at the DoD will use this information to decide whether or not to proceed into the Full-Scale Development Phase. The initial Category I test plan is prepared during the Validation Phase, and certain parts of the plan are executed. Although the tests are conducted primarily by the contractor, the Air Force does participate in, evaluate and control the testing through the Systems Project Office. By the end of this Phase the "anticipated unknowns" should be isolated, described in quantitative terms, and essentially eliminated as problem areas. The "unanticipated unknowns" should be determined as well as possible, but many hardware interface problems must necessarily await actual evaluation in the real environment. Exhibit 2, Appendix D, provides typical comments from the respondents on the type of data and information which the test facility should and could provide to the decision-maker for his Ratification Decision.

All of the respondents see some useful role for the test facility during the Conceptual Phase. The comments of the experts are centered around the use of the facility for technology demonstrations, trade-off studies, feasibility studies, configuration evaluations, uncertainty and risk identification and preliminary design information. Only four of the 117 respondents were negative with regard to the extended use of the facility during the Validation Phase, and most respondents are of the opinion that the facility has its greatest pay-off during this phase. Three of the objections were concerned with the use of prototypes during this phase. These respondents felt that the facility contribution should primarily be confined to the Conceptual Phase, and effort here devoted to flight prototypes. Another respondent questioned the accuracy and validity of the facility test data to such an extent that he, too, advocated only prototype flight during this phase. However, the comments representative of most respondents in Exhibits 1 and 2, Appendix D, illustrate that these experienced aerospace personnel see a critical and necessary role for the test facility in support of management decisions. It is accepted that the test facility can be more than just the engineer's tool to provide research and design information; it can also be an effective means of measurement and evaluation and thus support the decision-making process. This hypothesis is supported to some extent in an AIAA Paper by Messrs. Wagaman and Yeager of the Mitre Corporation (11).

A few respondents made the observation that "the A-X is not the way to do it." The Air Force is presently developing the A-X specialized close air support aircraft via parallel development programs; both contractors will build a prototype for flight competition. Two arguments were presented. One held that the government lost too much control with a "hands-off" policy during the development of the prototype. It was argued that the government had too much invested and too much at stake to permit such loose controls. The other argument was that too much dependence is being placed on the

competition and flight tests to produce good results.

The author has discussed this parallel development concept with members of industry and can report good agreement on the following points. The competition between two companies sponsors extra effort; both companies are encouraged to place their very best personnel on the job and give the development program highest priority within the company. Minimum interference by the government monitors during development permits much better planning, implementation of plans, and use of technical personnel by the contractor. One contractor estimated that he could get 30% more technical effort out of his engineering force since they did not have to answer so many questions and complete so much documentation. On the other hand, most respondents agree that development funds are probably always going to be limited. There will likely not be enough money for two good development programs. Consequently, the competitive programs will be restricted in money, time, and use of the test facility (like the A-X). History has demonstrated that this has been the type of development environment that runs a high risk of producing unsatisfactory flight aircraft. It would appear that the benefits of competition do not compensate for lack of design data; two parallel but restricted development programs are not as likely to produce a good aircraft as one thorough development program. Those who commented were hopeful that the A-X program would not befall these ills since it is a relatively straightforward and conventional design.

Some respondents made a recommendation for competition between scaled aircraft models (model fly-offs) in the wind tunnel during the Validation Phase. The author has pursued and developed this idea in interview with industry personnel and found very good acceptance. This approach brings together many of the suggestions made by the respondents, provides a competitive atmosphere, yet does not incur the expense of the competitive flight prototypes. It is suggested that the competing contractors provide an aerodynamic model (as per specifications) to the government as

part of their proposal. The model should represent the contractor's best estimate of his proposed final design. The government personnel would evaluate the competing models in the best government facilities available and thus assure that facility data and corrections were common. The test results would become a part of the contractor's proposal and be included with the remainder of the evaluations. The contractors seemed to feel that this procedure is fair and provides evidence to permit selection of the best aircraft. This is evidently a compromise proposal; the assumption is that development funds will not permit competitive prototype design and fly-off of advanced or large aircraft, and will not permit competitive and thorough development programs for conventional aircraft. At present, it is extremely difficult for the government evaluators to determine the best "paper" aircraft when each potential contractor presents data which has been accumulated from different (and sometimes inadequate) test facilities and subjected to various corrections.

It should be noted that the idea of competitive wind tunnel fly-offs has already been tested to a limited extent by the Air Force and is reportedly planned by NASA for the Space Shuttle Project. Although some success may be claimed, better control of the variables as suggested by the respondents should improve the usefulness and effectiveness of the method. It was mentioned by one respondent that competitive fly-offs might also be applicable for the Conceptual Phase for differentiating among concepts and ascertaining impartial estimates of risk and probability of meeting operational requirements. The author agrees that extension of this philosophy to the Conceptual Phase may very well be worthwhile for an expensive and/or technically complicated development program.

Management of the Evaluation Function

The test facility already plays a substantial role in aircraft development, and in the future may play an even more important role. Since data

from the test facility can be used to measure progress and can influence program continuation, it behooves the Air Force to give some attention to the process by which validation information from the test facility is interpreted, evaluated and passed to the decision-maker. It is suggested that existing procedures within AFSC do not always permit the processing of such validation information with the necessary objectivity and freedom from bias.

The test and evaluation functions have recently been addressed by a distinguished panel in a study of the DoD and its operating procedures for the Secretary of Defense and the President. The report on this study is commonly called the "Blue Ribbon Report" or "Fitzhugh Report" (named after the chairman, Gilbert W. Fitzhugh). The following is quoted from this document:

> In connection with test and evaluation, it should be emphasized that responsibilities for any evaluation function must be exercised independently. When they are subjected to or combined with responsibilities for the development of the item or subject being evaluated, the requisite objectivity is seriously jeopardized. (12)

In a report from the Air Force Propulsion Laboratory, the following recommendation was made with regard to aircraft engine testing procedures:

> The Test Center must not be subjected to influence or pressure from the system's contractual biases relative to the determination of contractual performance points. (13)

These remarks demonstrate the awareness on the part of knowledgeable observers that the evaluation of the aerospace system's development progress may be subject to prejudicial influence by those interested in demonstrating development objectives.

In Question 14, Appendix B, the respondent is introduced to the problem of getting unbiased information to the decision-maker. He is particularly asked to suggest an appropriate procedure for analyzing and reporting on experimental data from the wind tunnel that is to be used in ascertaining compliance with expected performance (as suggested in the

responses to Question 13). At least three parties are to be included in the discussion; i.e., the contractor, Systems Project Office, and DoD Test Center. Some of the responses are quoted in Exhibit 3, Appendix D. The author has attempted to include replies which are representative of many points of view. A large number of responses have been reproduced to give the reader some knowledge of the breadth of opinion and depth of feeling on this subject.

A very few of the respondents have denied existence of the problem; these few were quite defensive and argued that professionalism and individual integrity would not permit such biased information. However, most of the respondents did acknowledge the existence of the problem; they claimed that optimistic interpretation of validation information may always be expected from those who are trying to "sell" a particular program or who have a very close and vested interest in the program. Some respondents noted examples from their own personal experiences; however, these have been omitted to preserve respondent anonymity.

It is impossible to summarize the many individual ideas given in response to Question 14. The suggestions usually involve several thoughts or actions, and an attempt to group them into representative categories has proven unrewarding. The author has chosen, instead, to analyze the objectivity of the participants in the evaluation process and to point out certain ideas that are contained in many of the proposals. Some of these thoughts will serve as the basis for recommendations to be proposed later in this chapter.

It is not intended to imply that any group has more or less honesty and integrity than any other. One would only expect that the involved and interested party would make optimistic interpretations of data if that meant conformity with specified performance levels, especially if program continuation depended upon such interpretations. It must be acknowledged that data from the test facility are sometimes subject to a wide range of

interpretation, depending primarily upon corrections which may be applied to the data. The contractor's role and incentives need no explanation. He has much to lose if a program is cancelled prior to the Production Phase. The SPD usually finds himself in a position where he is trying to maintain a development program with time and money limitations which permit only success at each step of the development process. The pressure to meet predetermined objectives and maintain schedule is enormous; the alternative is to ask for more time and/or money. This is too often interpreted as "bad management." The government test facility personnel are usually thought to have no direct pressures which would jeopardize their objectivity. However, the pressures brought about by operation of the Test Centers under service funding have modified this position somewhat. Cancellation of a development project can result in closed facilities and loss of jobs. It seems then that all parties involved in the evaluation process have some "vested interests" which could reduce their objectivity.

Several suggestions were made by the respondents which included the use of "outside observers" for interpretation and evaluation. Unfortunately, uninvolved individuals and groups often do not have the depth of detailed knowledge to make good decisions. Although advisory groups have proven valuable in the past and most certainly will in the future, their use does not represent a complete solution to the problem. It appears that the more profitable approach to this problem involves a modification of procedures to increase the objectivity of the knowledgeable and involved parties where possible.

Some of the philosophy used in the development and qualification of propulsion systems seems appropriate for the aerodynamic portion of the evaluation process. It is understood and accepted by all parties that the engine will meet certain specifications--some determined by established documentation, others added for the particular engine. The Air Force Propulsion Laboratory recommends that the evaluation tests on

engines be performed in government test facilities (13). The government test facility personnel interpret the data and make corrections to account for facility or test pecularities. There are sometimes disagreements between the contractor and test personnel on the test data, but these are hopefully resolved with the assistance of the SPO on a technical basis.

Several respondents have suggested that specifications and minimum acceptable performance criteria should also be established for the aerodynamic portion of each aircraft development program. These broad specifications and areas for investigation could be defined for each decision-point milestone as noted by the responses in Exhibits 1 and 2, Appendix D. Additional details would be required to match the needs and problem areas of the particular aircraft. It is important that all anticipated problem areas involving acceptable data limits, data correction techniques, etc. be resolved among parties early in the program before a specific conflict arises. Such agreements, removed from the pressure of an immediate and critical decision, should add much objectivity to the results.

There seems to be good agreement among most respondents that the government should determine compliance of the contractor's product in government facilities. There is also agreement that these facilities should be the best available to minimize misinterpretation of the data. Several respondents have noted that test facility personnel do not usually have the capability of analyzing data from the systems standpoint; i.e., translation of the facility data into aircraft performance data. However, it is expected that they should be in a position to attest to the validity of the data taken in the facility and to specify corrections to be applied to the results. The role of the DoD Test Center and test personnel is clarified somewhat by the responses to Question 21, Appendix B. The respondent is asked if DoD facilities could better serve the development programs by providing experienced personnel on-site to provide additional services; e.g., guidance on the test program, data analyses, recommendations,

etc. There were 67% affirmative responses and 24% negative responses. However, the question was evidently poorly worded, for the comments of the respondents indicated that most wanted the same thing. Most respondents do not want another NASA at AEDC; nor do they want test facility personnel trying to design aircraft. They do want test facility personnel to know their facility better; they want to be advised of the accuracy of the data that comes from the facility; they want to know the correlation with flight data; and they want to be advised on how best to establish tests for the facility.

Some of the contractor personnel have indicated a concern that they may become completely isolated from the evaluation process. They fear that their product may be poorly judged through misinterpretation of data by the government testers and evaluators. Since the contractor usually has the most detailed knowledge of the product being evaluated, his expertise and counsel is essential to the evaluation process. The contractor should have the opportunity to question the interpretations made by the government test personnel and SPO. It may also be appropriate to use outside technical advisory groups or experts to supplement the available expertise on some issues and to provide another opinion when issues are unresolved. The procedures outlined here are intended to apply for tests in DoD facilities. When testing is accomplished in NASA facilities, the interplay between the NASA test personnel, SPO and contractor becomes the important issue. The DoD test facility personnel should then become advisors to the SPO--both for establishing the test plans and interpreting the results of the test facility.

Recommendations

1. Almost all of the aerospace experts who have responded to this study recognize that a sound facility test program is essential for successful fulfillment of the DoD directives for systems development. It has been

demonstrated that this facet of policy implementation is not receiving sufficient attention and that there are strong influences which work against implementation.

RECOMMENDATION: AFSC should recognize and reduce the influences that tend to force an inadequate facility test program. Test program criteria and coordination procedures should be established to assure that the test program is not subjected to unacceptable compromises by other factors in the development program.

2. It has been shown that the test facility can provide useful and tangible information to the government decision-maker for his Program and Ratification Decisions. The appropriate utilization of the test facility during both the Conceptual and Validation Phases has been enunciated and illustrated with examples provided by the respondents.

RECOMMENDATION: Milestone criteria which can be demonstrated in the test facility should be established for the Program and Ratification Decisions. All anticipated problem areas involving acceptable data limits, data correction techniques, etc. should be resolved as well as possible among the contractor, SPO and test facility personnel early in the program before a conflict arises. The contractor's product should be evaluated in government facilities by government personnel. The test facilities should be adequate to prevent misinterpretation of the data and argument over the results.

3. The Fitzhugh Report (14) recommends that a separate Defense Test Agency be created within the DoD to perform the functions of overview of all defense test and evaluation. It is not clear whether test facilities like those at AEDC would be a part of the new Agency, since emphasis in the report is placed more on operational testing than functional or engineering testing. However, if the recommendation is implemented and

such facilities are included, the evaluation role of the government test facility will be somewhat determined. Until that time, it appears appropriate to modify procedures within AFSC to reduce or resolve the dilemma of conflicting interests in the evaluation process.

RECOMMENDATION: <u>Attention should be given to more separation of the development and evaluation functions within AFSC. Test personnel should be removed when possible from the pressures which are inherent in the development process, but which act to force loss of objectivity in the evaluation process.</u>

4. Most respondents do not expect competitive full-scale aircraft flight demonstrations to play a significant role in most future development programs. This attitude is caused primarily by knowledge of the large expense of such dual development programs for technically advanced and large aircraft. Yet it was generally agreed that analyses alone provide insufficient evidence to permit selection of a contractor and the "best aircraft." A compromise position which involves competition between aerodynamic models in a government facility was accepted by many respondents as a desirable addition to criteria for selection of a contractor.

RECOMMENDATION: <u>Competitive demonstrations of contractors' aerodynamic models in government facilities should be given strong consideration when full-scale competition is not feasible.</u>

5. It was noted by several respondents that the DoD Test Center (AEDC) personnel do not provide some of the services required by their customers.

RECOMMENDATION: <u>AEDC test facility personnel should possess (or develop) the expertise to advise the aircraft contractor and SPO on the validity of the test facility data and to specify corrections to be applied to the results. This is expected to require more emphasis on the correlation of facility data with flight results.</u>

6. The Secretary and Deputy Secretary of Defense have made the point that the SPD should have the authority and flexibility to exercise more of his own good judgement to develop new weapon systems. It is expected that the SPD must be able to cut through the "red tape" and not be victimized by bureaucracy (15). Good management principles dictate that this decision-making authority carries with it the responsibility to hear the analyses and recommendations of the appropriate technical experts in supporting AFSC organizations. The comments given the author lead to the conclusion that this has not always been the case. Although the modern SPO and ASD are staffed by some of the more qualified military and civilian Air Force members, it is impossible for them to represent the technical expertise available in the supporting Air Force organizations. Unfortunately, the suggestion to "force" more coordination between the SPO and the supporting organizations has been interpreted by some of the affected respondents as more bureaucracy and limitation of the SPD's authority and flexibility.

RECOMMENDATION: Contributions from the Air Force organizations which support the SPO should be more automatic; i.e., provided without request of the SPO. More specifically, AFSC Supplement 1 to AFR 80-14 should be modified to make test centers responsible for certain advice, analyses and reports without the SPO specifying such a requirement. Such directives must be carefully worded so that the supporting organization remains responsive to the changing needs of the SPO.

7. General George S. Brown, AFSC Commander, has emphasized that he wants to identify "losers" among the new weapon systems under development as soon as possible and divert the funds to "winners" (15). The evidence obtained in this study indicates that a critical appraisal of facility test results and comparison with specifications is the best way to make such an early determination. The option is open to drop the

system, modify the specifications, or continue development. But, the decision-maker cannot always expect to have the necessary information for his decision if the program is "sold" to him by its advocates. He must have advantage of unbiased data to make his judgement.

RECOMMENDATION: When there is an unresolved difference of opinion between the Test Center and SPO regarding interpretation of critical test data, the Test Center should have the opportunity to submit a report of the circumstances to the Commander, AFSC. This should not be construed as an attempt to by-pass the authority of the SPD to make decisions. It is, instead, a "safety valve," an incentive for better coordination and agreement at lower levels, and a means for getting more objectivity into the analyses.

CHAPTER V

THE ADEQUACY OF TEST FACILITIES

There have been statements in previous chapters by contributors to this study who have either directly or indirectly questioned the adequacy of today's aeronautical test facilities. The respondents' concern with the facility's inability to predict the "real world" of flight and the uneasiness expressed as a result of extreme data adjustment and "correction" may be interpreted as an indication of ineffective test results and facility inadequacy. The role that the test facility is playing in the system development cycle and the role that it is expected to play in the future demands that the data from the test facility be accurate and believable.

Unfortunately, facility construction and modernization is not keeping pace with the increasing test needs dictated by more sophisticated, high performance and large aircraft. A review of recent history will reveal how this situation has arisen. Most of the large government test facilities of modern vintage were completed in the early 1950's. It was after World War II that concern was expressed in this country over the advanced state of aeronautical technology in Germany, and the situation was attributed primarily to their vastly superior wind tunnels and other environmental test facilities. An investigating committee headed by Dr. von Karman produced a report (16) which recommended the construction of several facilities; this resulted in the creation of the Arnold Engineering Development Center in Tennessee and several new NACA (now NASA) facilities. Fortunately, these facilities were designed with great foresight and imagination; they have served well for almost

two decades. Unfortunately, the availability of good test facilities has become such an accepted fact that it is sometimes difficult to convince those not closely associated with test facilities that the facilities are often less than adequate.

In this chapter, the nature and seriousness of facility inadequacies and some possible remedies are explored. It is hypothesized that deficiencies in environmental simulation in aeronautical test facilities have had detrimental effects upon systems development, and that these effects are growing worse with increasing time. Specific examples to illustrate this cause-effect relationship are solicited from the aerospace experts. It is further hypothesized that facility deficiencies are subtly causing compromises in aircraft design because of the designer's awareness of and dependency on available test capability. The roles of the contractor-owned and government test facilities are investigated, and the adequacy of the Air Force policy regarding construction and use of contractor facilities is questioned. Finally, the workability of the process for acquisition of major test facilities within the Air Force is contested.

Consequences of Test Facility Inadequacies

It is hypothesized that the deficiencies in environmental simulation in aeronautical test facilities have had detrimental effects upon systems development. The hypothesis is posed in Question 15, Appendix B, and the respondent is asked to indicate his agreement. The results are shown in Table 13.

Nine per cent of the respondents believe that facility deficiencies have so far had no detrimental effects upon aerospace systems development programs. Some of the "none" answers were qualified with comments such as the following: "The answer is based on what facilities presently exist and the marginal cost associated with simulation improvement.

TABLE 13

REPLIES TO HYPOTHESIS THAT DEFICIENCIES IN ENVIRONMENTAL SIMULATION IN AERONAUTICAL TEST FACILITIES HAVE HAD DETRIMENTAL EFFECTS ON SYSTEMS DEVELOPMENT

Agency	None	Some	Much	Very Much	No Answer
Industry	6	40	8	0	4
ASD	3	10	2	0	3
Headquarters	1	5	1	0	0
AFSC Labs	1	6	2	0	1
AEDC	0	8	3	2	0
NASA	0	5	3	0	0
Other	0	1	2	0	0
Totals	11	75	21	2	8

Money to significantly improve environmental simulation could better be spent elsewhere." The author had not expected the respondents to argue the question, since the difference between the desired and actual magnitude of certain simulation parameters is a matter of record and well publicized. However, two of the respondents who answered "none" did not acknowledge the problem. One comment was: "We have more test capability (quantity and quality) than we can possibly use for the next ten years. There are a few minor exceptions." However, 64% have experienced some effect and about 20% believe there is much or very much detrimental effect on systems development as a result of facility deficiencies. Since the respondents are primarily composed of individuals who have been instrumental in either developing or testing most of the aircraft developed in this country during the last fifteen years, it would appear that the testing deficiencies are real and are causing undesirable effects. The extent and seriousness of these effects are impossible to determine from Table 13, so the respondents were requested to comment on specific deficiencies and give examples where aircraft development

programs have been adversely affected because of inadequate test facilities and poor environmental simulation. Almost all those who made comments chose to relate situations which represent present problems; i. e., the facility deficiencies exist today and are getting worse.

The deficiency most referenced was the lack of high Reynolds number capability at transonic speeds. The respondents noted serious deficiencies in the ability of the wind tunnel to produce results which would permit prediction of:

Full-scale shock/boundary layer interaction effects,

High-lift performance,

Transonic buffet boundary,

Tail Loads.

Most respondents agree that the inability to get Reynolds number near full scale for large subsonic aircraft is a problem. The specific aircraft program most often mentioned was the Lockheed C-141, where the facility inadequacy resulted in difficulties in predicting the chord-wise pressure distribution on the wing at high subsonic speeds, thus providing erroneous estimates for pitching moment and structural design.

Another frequently mentioned effect of a facility deficiency was the inability to investigate the areas of inlet-engine compatibility and nozzle-airframe integration. The F-111 had development problems in these areas which were difficult to cure because of scaling problems (model size, Reynolds number, sting corrections, and propulsion airflow simulation). This made it quite difficult to simulate the actual boundary layer, shock interactions and external pressures which are present on the full scale aircraft.

Although this study does not directly address the development of the propulsion system, the third most frequently noted deficiency was the inability of the test facilities to support development of larger and more powerful subsonic and supersonic turbofan and turbojet engines.

It was noted that undesirable compromises have already been made in engine evaluation in facilities, and that the situation is certain to get worse as engines grow in thrust and size.

Another often mentioned inadequacy in facilities was the almost complete lack of good development facilities for hypersonic aircraft (i.e., above a Mach number of 5). It was noted that uncertainties in heat transfer data are impacting on the Space Shuttle development program. The inability to determine aerodynamic/thermodynamic interaction effects at these speeds concerns many respondents. It was the opinion of several that the development of hypersonic engines has been completely stymied by lack of adequate facilities. Again, Reynolds number simulation is inadequate in this speed regime as well. It was also noted that the development of higher performance re-entry vehicles for ICBM's has been essentially abandoned because facilities of adequate performance are not available. Dependence on flight testing has proven prohibitively expensive and has not provided the needed data.

A few of the other more frequently mentioned facility needs have been abbreviated and listed below:

-- Facilities which do not experience transonic blockage (at high angle of attack) for testing maneuvering aircraft.

-- Facilities which provide a low turbulence level for airfoil research.

-- Facilities which provide Mach/Reynolds number simulation concurrently for re-entry vehicles.

-- Facilities to develop VTOL/STOL aircraft--particularly for "power-on" testing.

-- Facilities to test spin characteristics of modern aircraft.

Many respondents have also provided some technical detail in support of their comments. Such detail is omitted for the purposes of

this report.

The preceding discussion should convince the reader that facility deficiencies are real and are causing problems in systems development. However, many respondents have also expressed concern over the inadequacy of testing techniques within existing facilities. Most users of the facility would like to see large improvements in ability to correct data for effects caused by the model mounting system, jet engine flow/wake, slotted and porous walls, etc. There is a strong demand for more emphasis on correlation of wind tunnel data with flight data. The respondents appear to be saying that there are many desirable and necessary improvements which can be made to enhance the quality of facility test data which do not necessitate new facility construction. It is unfortunate that more emphasis is not placed on such improvements, for the pay-off per dollar spent would be significant. However, this type of research has never been particularly popular, and recent trends toward reduced funding for testing facilities will probably further reduce such "overhead" expenditures.

Several respondents have noted that the effect of test facility deficiencies on past system development is inconsequential compared to what we may expect in the future. They say that such inadequacies are already causing technology to be stifled so that the knowledge available to the aircraft designer is less than required. Question 16, Appendix B, addresses this dilemma and asks the respondent what effect he expects on aeronautical systems development over the next decade if test facility capability is not improved. As one would expect from the discussion thus far, most respondents anticipate more costly and higher risk development programs and less than desired performance in future aircraft as a result of the testing deficiencies. Of course, specifics are dependent upon the directions that future aeronautical developments take in this country. As in the responses to the preceding question, a very few respondents have

not observed any facility deficiencies in the past and do not expect any in the future. Several replies reflect the "marginal" considerations of the expert. For example, the respondent may be in favor of additional facilities in "new" technical areas to provide options to the designer. However, he is against improving existing facilities with additional capability; to him it does not appear cost-effective or necessary on technical grounds. One respondent made the interesting point that the effects of higher risks and more costly programs brought on by facility deficiencies would further add to the disenchantment between the public/Congress and the military/aerospace industry. Some of the respondents' comments which represent the majority opinions are quoted below to illustrate the expected results of facility inadequacies in the next decade.

"The full benefits of potential aerodynamic breakthrough (e.g., supercritical airfoils) will not be realized because of poor simulation of flight conditions such that less than optimum performance will be obtained. Development programs will be more costly than necessary because of poor correlation between tunnel and flight testing--resulting in added tests to correct design deficiencies."

"Systems will likely require more extensive changes during flight development to achieve predicted performance."

"Unforeseen problems will be discovered too late for economical solution."

"Definitely more costly development, which will in turn limit the performance of aircraft, either through failure to meet specifications, or through lowered performance specifications designed to keep development costs from becoming excessive."

"Longer, more costly development programs producing less than optimum designs. Fewer programs because of budget constraints."

"Designers will play it conservative with little advanced technology. There will be some real bloopers that show up in flight-$ $ $ $."

"Structurally, the designs will be conservative--overweight and more costly."

"We will end up collecting the data in flight tests; i.e., the most expensive and least precise way."

A further hypothesis concerning the consequencies of test facility inadequacies is that this lack of test capability is subtly causing compromises in aircraft design because the designer is aware of the limits of facility capability and sometimes accepts a compromise design because he cannot verify new ideas with any degree of confidence. The hypothesis is addressed in Question 22, Appendix B, and the respondents' agreement is noted in Table 14. Fifty-six per cent of the respondents reject the hypothesis, 15% very strongly. Only 23% accept the hypothesis. Many of those who have disagreed listed numerous examples where large technical risks have been taken in previous aerospace designs without adequate facility support. However, many of those who agree with the proposition acknowledge the hypothesized tendency and some respondents admit knowledge of such compromises. A review of the comments just quoted in response to Question 16 will show that several of these comments indicate a concern over conservative designs and reduced advanced technology expected in future aircraft as a result of test facility deficiencies. The author concludes that the facility deficiencies are causing design compromise, though not yet very extensive. Such a trend has serious overtones, for it quietly leads to mediocrity. The problem is difficult to identify and correct, because it does not appear as a direct conflict between test requirements and facility capability.

The author has observed that similar tests are sometimes performed in different test facilities in an attempt to verify test data which is in doubt because of the uncertainty brought about by the extrapolation of simulation parameters. The respondent is asked in Question 26, Appendix B, to use his experience to make an estimate of the share of the modern test program that is motivated by such facility deficiencies. Note that the question excludes those tests performed in different facilities

to acquire different types of data. Only 44% of the respondents who completed the questionnaire of Appendix B answered this question quantitatively. The answers varied from 1% to 100%; however, all but three of the responses were between 5% and 30%. The author felt that the extreme three answers were a result of misinterpretation of the question, so they were dropped for treatment of the data. The data have a mode of 10%, a median of about 20%, and a mean of about 17%.

TABLE 14

AGREEMENT WITH HYPOTHESIS THAT FACILITY DEFICIENCIES ARE SUBTLY CAUSING COMPROMISES IN AIRCRAFT DESIGN BECAUSE OF THE DESIGNER'S AWARENESS OF AVAILABLE FACILITY CAPABILITY

Agency	Strongly Disagree	Disagree	No Opinion	Agree	Agree Strongly
Industry	8	24	9	16	1
ASD	6	8	3	0	1
Headquarters	0	3	3	1	0
AFSC Labs	2	7	0	1	0
AEDC	1	2	6	2	1
NASA	0	3	2	3	0
Others	0	2	1	0	0
Totals	17	49	24	24	3

The question of the previous paragraph was asked with regard to specific aircraft development programs in Question 18, Appendix C. The intent was to find the change in the answers with time, with the hypothesis being that the effects of facility inadequacies should be getting worse with increasing time. The data gave more of a "U-shaped" curve than a trend line. It is true that more of the modern aircraft development programs have experienced duplicate testing; however, in the early 1950's the lack of good transonic test facilities caused the same results. Of the

aircraft reviewed, 60% of the evaluators indicated duplicate testing of the aircraft of the 1960's; only about 30% of the evaluators indicated such testing for the pre-1960 aircraft. The magnitude of the estimates were close to those given in the last paragraph, with a mean of about 15%. It is tempting to conclude that the significant increase in duplicate testing in the 1960's proves the hypothesis. However, there are other factors which may influence the data. The types of aircraft included in each time period is important, for low-performance or conventional aircraft designs do not usually have this problem. The availability of more facilities and the opportunity to exercise such check-tests in the later time period may prejudice the data; or perhaps the data simply reflect a change in test philosophy. The author will only conclude from the responses that about 15% of the facility testing in modern aircraft development programs appears to be caused by the inability of test facilities to provide the desired simulation parameters. The primary cause given by most respondents for duplicate testing was inadequate Reynolds number.

Many of the responses to the questions concerning facility inadequacies were qualified or appeared to be somewhat guarded. Although most of the respondents acknowledged the facility deficiencies and the problems they are causing, they seemed concerned that this problem would be taken out of perspective with some of the other facility-related problems. The respondents' advice (as interpreted by the author) is to attack the problems associated with test facilities in the following order of priority:

1. Make better use of existing facilities through better and more timely test programs.
2. Perform the necessary studies and experiments to permit better extrapolation of data from existing facilities to the flight environment.

3. Build those few well-identified facilities where there is general agreement on the deficiency and need for the data.

Contractor and Government Owned Facilities

Most of the airframe industrial contractors have their own aerodynamic test facilities. Although some contractor test facilities are more extensive than others, they are all usually "small and inexpensive" when compared with the large development test facilities available within the government. The theory has been that a contractor needs readily available facilities in his own backyard for a large quantity of preliminary cut-and-try testing. It is expected that further downstream in the development program additional refinement and evaluation of design will require more sophisticated test facilities which are beyond the financial capacity of a single contractor. The government (primarily AEDC and NASA) has assumed the role of providing this more expensive "national" test capability; however, there are alternatives to this situation. The now defunct Southern California Cooperative Wind Tunnel was jointly owned and used by several companies and operated by an independent organization (California Institute of Technology). It was a rather large and extremely productive wind tunnel until the "missile era" caused its demise. A sister facility exists at the Cornell Research Laboratory and is operated for any user on a profit-making basis.

The respondents have been questioned to determine their position regarding the "types" of facilities industry and government should possess, and to establish some consensus on the roles of the industry and government facilities in aerospace development programs. Question 17, Appendix B, seeks to determine agreement with the situation where industry has the high-use/low-cost facilities and government has the high-cost/low-use facilities. The respondents' answers are noted in Table 15. Some of the respondents correctly point out that the government facility

does not necessarily have to be low-use because it is high-cost. The author intended for the "use" terms to apply to an individual development project, not to refer to overall utilization of the facility. One would expect the few sophisticated facilities to be used by a number of different projects feeding in from the many "low-cost" facilities. The seemingly substantial endorsement of this proposition (80% agreement) must be interpreted with care, for there are many qualifications among the agreements. Some of the comments given in response to Question 17 have been analyzed and are explained in the following discussion.

TABLE 15

RESPONDENTS' AGREEMENT WITH PROPOSITION THAT INDUSTRY POSSESS HIGH-USE/LOW-COST TEST FACILITIES AND GOVERNMENT PROVIDE LOW-USE/HIGH-COST TEST FACILITIES

Agency	Disagree Strongly	Disagree	No Opinion	Agree	Agree Strongly
Industry	2	2	6	32	16
ASD	2	2	1	10	3
Headquarters	1	1	1	1	3
AFSC Labs	0	0	0	8	2
AEDC	0	4	0	8	1
NASA	0	0	0	3	5
Other	0	1	0	2	0
Totals	5	10	8	64	30

Almost all industry respondents believe that industry should have its own low-cost backyard facilities. They argue that such facilities provide quick response and flexibility to the contractor, and are the key to industry research and contractor funded early development prior to government involvement. Industry claims that without their own facilities to support innovative development and provide immediate access for investigation of design problems, the development programs would

increase in cost because of unavailability of government wind tunnels, higher cost of obtaining data, remote site inconvenience, etc. Most of the government respondents also agree that industry should have these low-cost backyard facilities, but sometimes with resignation rather than the enthusiasm shown by industry. Most government respondents believe that the "contractor owned" facilities are essentially paid for by the government as the charges and over-head are prorated over a number of aircraft development projects. There is a strong feeling within the government that there are presently too many contractor facilities and not sufficient work to keep the facilities busy. It is argued that contractor facilities are not as readily available to all potential users as those operated by the government (primarily, because of proprietary considerations). There is substantial agreement among government respondents that the government needs better control on the number of such facilities at industrial sites developed indirectly with DoD funds. Yet, most government respondents concede that these facilities are part of the present system of development, represent a part of our national capability to develop aircraft, and therefore should be used. Some government respondents (particularly those associated with research) point out that the government also needs some low-cost research facilities to support in-house research.

The industry agrees that no single contractor should have to provide the type of high-cost facility usually supplied by the government. However, a few industrial respondents would rather see several aircraft companies fund and support a large cooperative wind tunnel than have the same constructed and operated by the government. They argue that they are not in favor of the government taking over a role which they believe to be properly that of the contractor. They claim better response and cheaper data from such cooperative tunnels. However, most industrial respondents accept the government facilities as fulfilling a useful

role and have come to depend upon them.

The government respondents indicated good agreement on the handling of large test facilities; i. e., they believe in government ownership and operation and explain that the large test facilities are often one-of-a-kind and everyone should have access to them. Most government respondents believe that the government must have these sophisticated tools to evaluate and validate the contractor's product; i. e., the government must insist on qualification of critical components in its own facilities. Many feel that the government would indirectly pay for the cooperative facility even if the contractors pooled their own funds to build it. In fact, some argue that it is not a question of who pays for the industry test facilities, but only a matter of how they are funded.

It is hypothesized that the contractor-owned aeronautical test facilities assist the company in obtaining government contracts. The respondent is asked to review his experiences and express his opinion on the degree of influence the contractor's test facilities have on contractor selection in the first part of Question 19, Appendix B. The results are shown in Table 16. All agencies agree that the contractors' test facilities are an important part of his competitive "strength" as he vies for aerospace development contracts. With such strong conviction on the part of both the industrial bidder and government evaluator as to the importance of the contractor's test facilities, there can be little doubt that industry is provided with an incentive to continue to build test facilities and even compete to provide the "best" facility.

The second part of Question 19 probes a somewhat more discriminative position; i. e., does the response in Table 16 hold true even though the same test capability is available for the company to use at a government test facility. See Table 17 for the answers. It would appear that the availability of government facilities to perform develop-

ment testing has little or no influence on a contractor's incentive to provide his own facilities and even duplicate government test capability. It may be concluded that a very competitive situation has been created which tends to expand the contractor facilities.

TABLE 16

RESPONDENTS' AGREEMENT THAT CONTRACTOR-OWNED TEST FACILITIES ASSIST THE COMPANY IN OBTAINING GOVERNMENT CONTRACTS

Agency	None	Some	Much	Very Much	No Answer
Industry	4	19	17	17	1
ASD	1	9	2	6	0
Headquarters	0	4	2	1	0
AFSC Labs	0	2	5	3	0
AEDC	0	5	4	4	0
NASA	0	2	2	4	0
Other	0	1	2	0	0
Totals	5	42	34	35	1

TABLE 17

RESPONDENTS' AGREEMENT WITH HYPOTHESIS THAT COMPANY-OWNED TEST FACILITIES HELP THE COMPANY IN OBTAINING GOVERNMENT CONTRACTS EVEN THOUGH THE SAME TEST CAPABILITY IS AVAILABLE FOR COMPANY USE AT A GOVERNMENT TEST FACILITY

Agency	Yes	No	No Answer
Industry	49	2	7
ASD	15	1	2
Headquarters	6	1	0
AFSC Labs	10	0	0
AEDC	13	0	0
NASA	7	1	0
Other	3	0	0
Totals	103	5	9

As long as the aerospace business has been prosperous, both the government and industrial facilities have had sufficient workloads to prevent a conflict from arising. Now that there is a depression and the testing workloads are substantially reduced, it has become evident that the quantity of facilities (though not quality) surpasses the need. Government managers have begun to seek controls to curtail construction of facilities at industrial sites and to direct testing to government facilities. Operation under service funding within AFSC (particularly AEDC) has further encouraged efforts to direct development testing on AFSC programs to Air Force test facilities.

For quite some time the government has had a policy which would limit construction of new facilities at a contractor's plant and direct testing to AFSC facilities. The following are quotes from AFSC Supplement 1 to AFR 80-14:

> "Priority will be given to accomplishing tests at AFSC installations."
>
> "Use of other agency or contractor facilities will be limited to those efforts which cannot be accomplished in AFSC facilities or which, in the best interests of the government and the program should be accomplished elsewhere."
>
> "To promote multiprogram use and the development of AFSC capabilities, new facilities will be located on AFSC installations unless there are clear and compelling reasons for their location elsewhere." (6)

The reader will observe sufficient freedom in each of the three quotes above to permit a wide latitude in implementation of the policy. The test facility construction referenced here is that which would support and be funded by a particular aircraft development program.

Although deep concern has been expressed by many government respondents regarding the continued proliferation of test facilities by industry, the government has no direct control over industry in this regard. If an aircraft company feels that it needs a test facility, de-

termines that it will be placed in a better competitive position with the facility, and is willing to risk its own funds to build it, the government has no authority to say otherwise. The only control which the government might exercise is the "weight" given for the facility in evaluation of a bid proposal, acceptance or non-acceptance of overhead for the facility in a contract, and permission to use the facility in a military aircraft development program.

There appears to be no set of solutions to the problems created by declining test workloads and the resulting excess in availability of certain types of aerospace facilities. The smaller the development workload gets, the more difficult even a compromise position becomes. However, the respondents have freely shared with the author their opinions and feelings concerning these forces and events. Perhaps an explanation of some of these views will permit the reader to better understand the situation and accept the recommendations to be presented later in this chapter.

The contractor argues that he is sometimes forced into AFSC facilities (AEDC) that are too big, sophisticated and expensive for his test needs. He claims savings in cost and time by being able to go to test facilities of his choosing which provide only the information required. Further, he would like to use his own test facilities as much as possible; they are convenient and this is the way he pays for them. The SPD tends to agree with these arguments by the contractor. He is usually laboring under limited funds to develop an aircraft; he certainly does not want to spend extra dollars for test data if it can be obtained at less cost. The fact that NASA can provide testing at no charge to the SPD (see Chapter III) further complicates the situation. Many industrial and ASD respondents deeply resent the fact that they are being forced to AFSC facilities, as they say, "to keep them open."

Now for another point of view; one which does not really contradict

the views expressed above, but one which leads to different conclusions. The AFSC owned and operated test facilities represent a very substantial investment; overall, they are the best and most capable facilities available for aircraft development. Proficient test crews have been assembled and represent a valuable resource to the nation. The government facilities are required for verification and qualification of the contractor's product; attempts to ignore this step have sometimes led to unsatisfactory and expensive consequences. The unfortunate situation is that there just is not enough test work in today's aerospace environment to keep all the facilities busy; all are going to suffer, some more than others. The government facilities must maintain sufficient workload to keep together an experienced technical workforce; if this is diluted, their effectiveness and an important national capability is lost. Even though the SPD may feel that he is sometimes spending more money for testing, from a larger viewpoint the Air Force may actually be spending less. Since the government facilities must be maintained for the reasons stated, it costs very little more to use them fully than only partially. It is only the accounting system that makes their use appear uneconomical.

A review of the results of Question 18, Appendix B, will conclude the discussion of government and contractor owned facilities. The question assumes agreement of some division between contractor and government facilities. It asks the respondent for his estimate of this dividing line in terms of facility construction costs, or requests suggestions for some other designation of a division. A few respondents from both industry and government indicated their belief that industry should build what it feels it can afford. They argue that the facility should depend upon what program it is expected to support, what future use is expected, etc. A few respondents suggested a dividing line based on charge rate; i.e., cost per hour of operation. Over one-half

of the respondents claimed no opinion, and 49 respondents provided an estimate based on construction cost as requested. The results ranged from one-half million dollars to 25 million dollars. The data have a mean of 7.4 million dollars, a median of just under 5 million dollars, and a mode of 5 million dollars.

The Test Facility Acquisition Process

It does not appear that the government is fulfilling its role in providing the new, more sophisticated aeronautical test facilities as expected by the aerospace community. Yet, it was demonstrated earlier in this chapter that the requirement for certain test capability is well recognized within both government and industry, and that deficiencies in the test facilities have caused and are expected to cause undesirable effects in aircraft development programs. It is the purpose of the following discussion to explore the circumstances that have produced this state of affairs.

It is during the Conceptual Phase of development (see Figure 1) that system planners first direct their attention to the test facilities that will be required for support of a particular system's development. It is after an affirmative Program Decision that serious attempts are begun to provide these facilities. As shown earlier, much facility testing is required in the Conceptual Phase and a very important role is played by the facility in several capacities in the Validation Phase. Several aircraft designers have declared that their design progress is usually paced by data from the facility. Clearly, no test facility construction or improvement sponsored by a new system can provide help for that system in the Conceptual Phase testing. Because of the time it takes to design, construct and check-out a facility, the same can be said for the Validation Phase (except for rapid and usually minor modifications). It is

obvious that the facility development cannot parallel the aircraft development; a major new test facility may require five to seven years to design, construct and bring to operational usefulness.

The only channel available for acquisition of major test facilities within the Air Force outside the systems acquisition cycle is the Military Construction Program (MCP). This program provides funds for all types of construction at military installations (buildings, equipment, appurtenances, utilities, etc.). Submittal through this channel takes the technical facility out of direct association with the systems it would support and, to a large extent, out of the environment where its need is recognized. A multi-million dollar facility does not appear overly expensive in a multi-billion dollar system's acquisition program, but its cost does look sizable when compared with that of most other construction items in the MCP. Approval of a single, large technical facility within the MCP would necessarily result in disapproval of many less costly items; such a decision would undoubtedly be unpopular in view of the limited resources in the MCP. Further, since the test facility is necessarily "justified" by technical trends and planned future development programs, it usually has the appearance of a future and indefinite need, while the other MCP items demonstrate a more immediate need. Thus, large test facilities are rarely accepted by the decision-makers in the MCP. The reason most often given for disapproval by the higher echelons is that the proposed facilities "do not support an 'approved' development program." Such a rationale has completely closed the loop to deny major facility acquisition through either the systems development cycle or MCP. This situation is briefly explained in Question 20, Appendix B, and the respondent is asked to suggest methods for planning and funding large aeronautical facilities, while at the same time minimizing the risk of building facilities which are not needed.

Most of the respondents were already aware of this situation and offered a reply. All but three acknowledge the seriousness of the implications. The author is aware that many of the suggestions have already been tried with little or no success, and it does not appear worthwhile to tabulate the responses. However, some of the comments fall into a few main themes which will be discussed.

Many respondents point out that the existing test facilities at NASA and AEDC could never have been built under the present approval/funding system. Yet, most major facilities are still operating 15 to 20 years later and have contributed significantly to aeronautical successes in this country. Hundreds of system development programs have passed through these facilities; they are not "one-system" facilities. The major test facilities have been and should be designed to provide basic and flexible capability, so that inexpensive and quick modifications can accommodate new systems' development needs. Such a design philosophy is expected to minimize the possibility of designing a "special purpose" test facility that might have a short-lived need.

There were numerous suggestions for various types of committees, composed of industry and government representatives, which would plan, endorse and sponsor new test facilities. It is likely that many readers have served on or supported such committees in the past. Several industry respondents feel that industry has not been permitted to make sufficient contributions to facility planning in the past; they acclaimed this study on test facilities as a "large step forward." However, the respondents acknowledged that although committees serve a useful role in coordinating requirements and focusing attention on the needs, they are usually endowed with only the power to make recommendations. The implementation of these recommendations often puts the problem back into its original context.

A few respondents believe that the Fitzhugh Report's (14) sug-

gestion for the creation of a separate Defense Test Agency will be the solution. They expect this new attention at DoD level to resolve the existing approval and funding problems for test facilities. Several respondents expressed a belief that the most significant act to assure adequate test facilities and proper operation of the facilities would be to bring together the major government test facilities (AEDC and NASA) under one control.

Many respondents believe that this situation is only another manifestation of poor DoD-AF planning in general. Perhaps "poor planning" is not correct terminology, for it implies that the planners are doing a poor job. This may not be true; the critical problem appears to be that no one in the system has confidence in the plans. Everyone is aware that due to changes in political parties, public opinion, Congressional attitudes, DoD and AF fluctuations in priorities, and threats from other countries, certain portions of any plan will be invalid. It is concluded by some government decision-makers that a substantial financial investment (like large test facilities) based on such plans is too risky; they want to wait on a "sure thing." It is this type of thinking and interpretation of plans that has prevented acquisition of aerospace test facilities whose need has been acknowledged by all the aerospace industry.

Recommendations

1. The evidence gathered in this investigation demonstrates that Air Force policies and practices have helped to establish a competitive environment which encourages the aerospace industries to construct test facilities. The caliber of the potential contractor's test facilities is influential in determining his ability to obtain Air Force development contracts. This situation has resulted in the proliferation of test facil-

ities among contractors; the capacity for certain test capability surpasses the need. The recent aerospace recession has amplified the results of this oversupply. To be effective, test facilities must operate with skilled and experienced personnel and must have some continuing improvement and adjustment to meet changing test requirements. Because of this rather "fixed" overhead, test costs are lowest when a test facility is operating at capacity workload. The proliferation of test facilities within industry (and to some extent among government agencies) has resulted in two significant trends:

a. The funds being spent for new facilities are too often used to supply redundent test capability, while the real need for new and advanced test capability is going unfilled.

b. The reduced test workload, when divided among many facilities, makes it uneconomical for each facility to maintain the experienced test crews and updated test techniques required for good test results.

RECOMMENDATION: The Air Force should review the usefulness of incentives which encourage the contractor to purchase test facilities. Air Force policy should be established which more clearly defines the use of the government facilities in the development cycle and which provides boundaries that better control the competition among contractors for test facilities. The contractor should not be rewarded for unwarranted duplication of test capability and must be advised that he will be expected to use government facilities where possible in development of Air Force aircraft. Until the problem of test facility oversupply is reduced, the Air Force must maintain a sufficient workload at its own test facilities to assure its capacity to develop new aircraft and evaluate contractor performance. Some of the information provided in this report may prove beneficial to those who attempt to revise AFSC policies.

2. Before the recent recession in the aerospace business, at least three aircraft companies were seriously considering building their own high Reynolds number facilities at costs on the order of 15-30 million dollars. It has been shown that both industry and government personnel expect the government to provide the larger and more expensive test facilities; it was further demonstrated that this particular test need has been well identified. Since the government had not been able to provide the required test capability through its cumbersome and ineffective facility acquisition procedures, the industries took the initiative. Certainly the competitive situation already explained had some influence on the industries' decisions to invest such large sums of money in facilities. However, if government had acted promptly to fulfill its expected role and provide the required capability, in all likelihood industry would not have planned to take such large risks. In an analogous situation in the early 1960's, many aircraft companies built rather expensive space simulation chambers; few of the test facilities have been well utilized.

RECOMMENDATION: <u>In addition to discouraging the use of industries' test facility capability in competition for Air Force contracts, the government must also take the lead in constructing new and advanced test facilities where the need is well recognized. Such a positive action can likely prevent construction of several similar facilities at industrial sites</u>.

3. It has been shown that there are well identified deficiencies in aerospace test facility capability and that these deficiencies are causing and will continue to cause detrimental effects in systems development. All attempted approaches to remedy this situation have so far proven ineffective. A decade or so of good facility capability appears to have resulted in lack of a workable system through which new test facilities can be

acquired.

RECOMMENDATION: Every possible avenue should be tried to provide the needed test capability. Efforts to fund major test facilities by special committees and through special channels should continue. In order to effect a more permanent solution to the problem, the planning function within AFSC and USAF should be revised to make consideration of the supporting test facilities an integral part of the systems planning procedure. The plans should be designed and accepted by Air Force management as guidelines for decision and action, with long lead-time items (like major test facilities) receiving prompt and priority attention.

4. The AFSC has a large portion of its capital investment in test facilities. The product or output of AFSC is largely determined by the use and adequacy of these test facilities. Yet there is little permanent expertise within AFSC to assure that the facilities are adequately planned, updated and used properly.

RECOMMENDATION: It is suggested that more expertise in the facilities area be permanently installed in both the planning function and MCP approval cycle within AFSC (and USAF).

5. The aerospace experts who have responded to this investigation have indicated that existing test facilities can be made more useful with minimal expenditure.

RECOMMENDATION: AFSC should give more attention (and funds) to improvement in testing techniques, data interpretation and correlation between test and flight data.

6. It appears that service funding at AEDC has resulted in the illusion of a "penalty" for use of the AEDC facilities which tends to reduce the

effectiveness of the test facilities and test personnel. Once Air Force dollars are divided into separate categories (development, facility operation, etc.) and careers and jobs are made to hinge on how well money is utilized within each category, it is all too easy to lose perspective of overall economy and endanger the goal of good aircraft development.

RECOMMENDATION: The problems associated with the use and operational funding of AFSC test facilities should be studied outside the influence of a particular aircraft development program. In particular, the costs of facility testing should be studied from an Air Force and national viewpoint. Charges to development programs for facility use at AEDC and NASA should either be standardized or eliminated. Service funding at AEDC should be halted to terminate the very undesirable side effects until the issue can be evaluated and resolved.

CHAPTER VI

CRITIQUE OF FACILITY TEST PROGRAMS

It is the intent of this portion of the study to bring as much objectivity and expertise as possible into the evaluation of the test facilities' role and usefulness through studies of specific aircraft development programs. Appendix C contains the portion of the questionnaire which was used to review and evaluate aircraft development programs which have been essentially completed. The respondents to these 25 questions are those individuals within the aircraft companies who were closely associated with the wind tunnel test programs during aircraft development and who have knowledge of the relative influence of the test program on the particular aircraft development cycle. The respondent was asked to provide historical data on the wind tunnel program, to evaluate the program, and then to rearrange the wind tunnel test program into a more optimal and productive form.

The author used the following criteria originally to select aircraft development programs for this analysis:

1. The portion of the development cycle which includes the "planned" wind tunnel test program must have been completed. This eliminated some of the recent military aircraft presently under development.
2. The aircraft must have undergone a "normal development cycle." This ground rule was applied in a negative sense to eliminate certain aircraft from consideration. For example, aircraft which are close follow-ons to earlier aircraft would obviously not require the same type or magnitude of facility

test programs as those which were brought through all the development stages. Therefore, an attempt was made to by-pass those aircraft which depended heavily upon the aerodynamic configuration of an earlier version of the aircraft.

3. The more recently completed aircraft development cycles were sought; i.e., post-1950 flight dates.
4. Pure jet-powered aircraft were selected. Propeller aircraft usually necessitate a different test program.
5. Representative aircraft from various categories were sought (i.e., fighters, bombers, cargo, light aircraft, military, and commercial).
6. A final and important criteria was that the data had to be available in the archives of the aircraft companies and had to be identifiable in the specified format. Furthermore, the expert evaluator had to be available to contribute to the study. And most important, the aircraft company had to be willing to provide the services of some important personnel for the study.

Only 16 of the initially selected 35 aircraft and aircraft development programs satisfy all of these criteria. The author found that no aircraft seems to follow a "normal development program"; every aircraft development is a special case with its own unique constraints, pressures and objectives. Needless to say, criteria Number 6 was most important; i.e., the availability of the data and the evaluator, and the ability and willingness of the company to participate.

The Boeing Company furnished very complete data on the use of

the wind tunnel in their aircraft development programs. However, these data were being gathered at a very critical time in the Supersonic Transport (SST) Program, and it was unfortunate that some key personnel were not available to evaluate the individual development programs as requested. The author did discuss these development programs in interviews, and several of the Boeing personnel stated that they were satisfied with the use of the wind tunnel. They explained that the wind tunnel usefulness was so well accepted at all levels of management that they usually had no problem in accomplishing as much testing as they needed. Because of these circumstances, the <u>actual</u> wind tunnel program has been equated to the <u>optimal</u> wind tunnel program for all the Boeing aircraft. The reader will observe that several of the wind tunnel programs from other companies also did not change; usually the program was successful and there was no reason to change. Sometimes the evaluator would reason that technical knowledge was limited at that point in time and a change in the wind tunnel program would not likely have improved chances of discovering certain design deficiencies.

The Boeing SST was included in these data, although it did not complete its wind tunnel program. Over 40,000 wind tunnel test hours had been accomplished at program termination, and the test program was projected to 43,400 hours at planned first flight (December 1971). This program was included because it represents an important and extreme set of data. The reader will find that the 35 aircraft include 4 propeller aircraft, 3 pre-1950 aircraft, 3 aircraft which closely follow the aerodynamic design of others, and one rocket-driven aircraft (X-15). The F-14, which does meet all of the criteria, was not included, for the company did not wish to release the data at this time.

Usually only one expert evaluator was available to complete the questionnaire for each development program. In the few cases where more than one estimate was possible, the data have been averaged and

entered as a single entry. Despite the difficulties of obtaining data of this type, the author estimates that about 75% of the available data have been accumulated. The quantity of aircraft programs in various categories is more than enough to prevent conclusions based on the data from being considered "special cases." Further, the reputation of the evaluators is so substantial that their observations can hardly be considered "just another opinion." The author believes that the opinion of such experts based on independent evaluations of so many samples represents the most unbiased and truthful data available.

Within this chapter the historical data on the wind tunnel programs is presented in as brief format as possible. The evaluations of the programs are summarized and illustrated with representative examples. Finally, the results of a multiple regression analysis are presented as part of a program to assist in the development of future wind tunnel programs. As the respondent is advised in the preamble to Question 3, Appendix C, this portion of the questionnaire is to include all aerodynamic or structural testing in wind tunnels, but to exclude development of the actual propulsion system. Propulsion-airframe integration type tests are to be included.

Comparison of Actual and Optimal Wind Tunnel Test Programs

Table 18 lists the 35 aircraft which will be used in various combinations in the following discussions. Also designated are the physical and performance characteristics which will be a part of the regression analysis (i.e., weight, thrust, and speed). More specific definitions are noted on the table.

Tables 19 through 22 are derived from information presented in response to Questions 3 through 8, 19 and 20, Appendix C. It is suggested that the reader orient himself with the intent of the optimal test program by reviewing the preamble to Question 19, Appendix C. Omission

TABLE 18

AIRCRAFT CHARACTERISTICS

Aircraft	Takeoff Gross Weight (1,000 lbs)	Maximum Total Thrust (1,000 lbs)	Maximum Speed (MPH)
XP-84	16.8	4.9	625
B-47	230.0	36.0	600
F-89B	42.0	14.4	635
B-52	450.0	84.0	635
F-100	28.0	10.0	770
F-3H	33.9	14.3	647
F-11A	24.1	10.5	890
F-101	47.0	29.8	1120
F-8	28.0	16.0	1000
F-105A	40.0	24.5	1254
KC-135	297.0	55.0	600
B-58	160.0	62.4	1385
F-106	35.0	17.2	1525
707	258.0	52.0	600
T-2A	6.9	3.4	490
F-4	54.6	33.0	1600
RA-5C	62.0	32.0	1385
T-38	11.8	7.7	860
880	184.5	44.8	615
OV-1	16.7	5.5*	325
X-15	36.4	50.0	5500
A-6A	54.0	17.0	720
E-2A	49.5	20.3*	297
727	161.0	42.0	600
C-141	316.1	84.0	550
B-70	500.0	180.0	2000
XC-142	41.5	26.2*	430
F-111	80.0	38.0	1650
OV-10A	14.5	3.6*	305
A-7	32.5	11.4	578
Gulfstream II	56.0	22.8	585
737	111.0	28.0	575
C-5	728.0	164.4	543

TABLE 18--Continued

Aircraft	Takeoff Gross Weight (1,000 lbs)	Maximum Total Thrust (1,000 lbs)	Maximum Speed (MPH)
747	710.0	174.0	640
SST	635.0	274.0	1800

NOTES:

1. Aircraft are listed in order of flight date.
2. Maximum total thrust is maximum static thrust with afterburner (if installed); i.e., total of all engines.
3. Maximum speed is at best altitude.

* Designates propeller-driven aircraft. Horsepower is converted to "equivalent thrust" by a factor of 2.5 lbs. thrust/hp

References 17, 18, 19, 20.

of data on the Tables means that it was not made available to the author. Although included on the Tables, the X-15 is excluded from the following analyses because of the late arrival of the data.

Table 19 identifies the date that the aircraft development program began. For the military aircraft, this is designated as the date the company was awarded a contract as a result of either a competitive or unsolicited proposal. It was not unusual for study contracts to have preceded this date. The actual wind tunnel test hours performed by the company prior to contract award (or program go-ahead) are recorded in the second column. Sometimes these tests were conducted as a part of a government-funded study; somtimes they were company sponsored as preparation for their bid proposal. The third column designates the number of test hours suggested by the respondent as the preferred or optimal test program for the same point in time. For the 26 aircraft represented in the optimal program, 17 respondents desired additional test hours at the program beginning, 7 saw no reason to change, and 2 suggested less testing at this early date on their program. In all 13 cases where the difference between columns two and three represents either a substantial number of test hours or significant portion of the total test program; the recommendation is for an increase in the quantity of wind tunnel testing at this point.

Table 20 presents the estimated date of "design freeze" on the aircraft development program. This is the date at which the wind tunnel could no longer make a significant contribution to the design of the first flight aircraft. This date was estimated by the author for the 8 Boeing aircraft on the list (one year prior to first flight), and the actual test hours at design freeze were then calculated from the data provided. The preferred test program is again shown in the third column. Seventeen respondents wanted additional testing accomplished at design freeze (not necessarily the same 17 respondents in the preceding paragraph),

TABLE 19

TEST HOURS AT BEGINNING OF DEVELOPMENT PROGRAM

Aircraft	Date Program Began	Actual Test Hours at Contract Award	Optimal Test Hours at Contract Award
XP-84	Jan 45	0	1000
B-47	- - -	---	- - -
F-89B	45	0	425
B-52	- - -	---	- - -
F-100	Nov 51	260	260
F-3H	Mar 51	1440	1500
F-11A	Dec 52	0	1500
F-101	51	0	1200
F-8	May 53	248	800
F-105A	51	0	2000
KC-135	- - -	----	- - -
B-58	Feb 51	0	0
F-106	July 55	0	0
707	- - -	---	- - -
T-2A	June 56	0	250
F-4	Oct 54	200	1000
RA-5C	July 56	2244	2244
T-38	55	0	600
880	June 56	0	0
OV-1	Ap 57	250	250
X-15	Nov 55	0	0
A-6A	Feb 58	526	600
E-2A	Oct 56	0	1000
727	- - -	---	- - -
C-141	Mar 61	235	1500
B-70	Jan 56	1082	3500
XC-142	Ap 62	1214	1000
F-111	Nov 62	4925	5000
OV-10A	Oct 64	430	400
A-7	Mar 64	1634	1634
Gulfstream II	Jan 64	0	150
737	- - -	---	- - -
C-5	June 64	1300	2500
747	-----	---	- - -
SST	-----	---	- - -

TABLE 20

TEST HOURS AT DESIGN FREEZE

Aircraft	Date/Design Freeze	Actual Test Hours at Design Freeze	Optimal Test Hours at Design Freeze
XP-84	Oct 45	1440	2000
B-47	Dec 46	2000	- - -
F-89B	47	1000	1625
B-52	Ap 51	4500	- - -
F-100	Sept 52	3555	3555
F-3H	Mar 53	2165	4500
F-11A	Dec 53	1800	3500
F-101	July 54	1972	2500
F-8	May 54	3020	3200
F-105A	May 55	5200	7000
KC-135	Aug 55	400	- - -
B-58	Sept 54	5673	6000
F-106	Mar 56	1565	2100
707	Dec 56	1000	- - -
T-2A	June 57	374	550
F-4	Nov 57	5014	4000
RA-5C	June 57	4579	4579
T-38	June 57	1822	3000
880	Sept 58	2069	2069
OV-1	Sept 58	2005	2005
X-15	Dec 57	3977	4000
A-6A	Dec 59	4476	4800
E-2A	Nov 59	5605	5285
727	Feb 62	3700	- - -
C-141	July 63	4282	5500
B-70	June 60	7955	13000
XC-142	Feb 64	6712	7000
F-111	Nov 63	11785	12773
OV-10A	May 65	1110	800
A-7	Jan 65	3657	3657
Gulfstream II	Oct 65	1124	2100
737	Ap 66	5400	- - -
C-5	May 67	7000	6000
747	Feb 69	11800	- - -
SST	Dec 71	40000	- - -

5 wanted no change, and 4 suggested some reduction in the program at this point. It may be noted that some of the changes are obviously just round-off approximations. It is significant that of the 15 changes that represent substantial test hours or a substantial portion of the total test program, 12 respondents asked for an increase of testing at this point. It will be observed that some of those who suggested a decrease in test hours for their program at design freeze, had performed a large portion of the test program at that time in the actual program.

Table 21 shows the same type of data for the event of the first flight. This table represents the most complete and exact set of data. Date of first flight seems to be well recorded; further, the actual test hours for the Boeing aircraft could be determined from the data provided the author. At first flight, the evaluators suggested 14 increases in wind tunnel test program, 7 decreases and 5 without change. For the 11 significant changes between columns (as described in previous paragraphs), 8 respondents suggested test program increases. Another comparison may be helpful; the 14 increases average 1,230 additional test hours each, while the 7 decreases average 676 test hours each.

The first two columns of Table 22 designate the actual and optimal total development test programs. This is not meant to include any testing in support of follow-on versions of the aircraft or retro-fit programs. The 3 aircraft which indicate significant overall test program increases are the F-3H, F-101, and B-70. In the latter case, this is the recommended test program if development were directed toward a production aircraft. Several aircraft programs show significant overall decreases in the test program, including the F-89B, XC-142, OV-10A and C-5A. Overall, seven respondents suggested increases in total development test hours and 12 suggested decreases. Column 3 of Table 22 shows the actual number of wind tunnel test hours in support of the development program after first flight. A large number of test hours here

TABLE 21

TEST HOURS AT FIRST FLIGHT

Aircraft	Date of First Flight	Actual Test Hours at First Flight	Optimal Test Hours at First Flight
XP-84	Mar 46	1440	2400
B-47	Dec 47	2850	----
F-89B	48	1000	2625
B-52	Ap 52	5200	----
F-100	May 53	4356	4356
F-3H	Dec 53	2478	7000
F-11A	July 54	2880	4000
F-101	Oct 54	2092	3000
F-8	Mar 55	5751	4400
F-105A	Oct 55	5200	7000
KC-135	Aug 56	600	----
B-58	Nov 56	8337	8000
F-106	Dec 56	2357	2500
707	Dec 57	1650	----
T-2A	Jan 58	435	550
F-4	May 58	5152	6000
RA-5C	Aug 58	7143	7129
T-38	58	4073	4000
880	Jan 59	2069	2069
OV-1	Ap 59	2165	2165
X-15	Sept 59	5400	4786
A-6A	Ap 60	4476	5000
E-2A	Oct 60	6797	6285
727	Feb 63	4075	----
C-141	Dec 63	4418	5500
B-70	Sept 64	13377	17000
XC-142	Sept 64	7213	8000
F-111	Dec 64	20587	20040
OV-10A	July 65	1180	900
A-7	Sept 65	3908	3908
Gulfstream II	Oct 66	1969	2150
737	Ap 67	6700	----
C-5	June 68	7635	6000
747	Feb 69	14000	----
SST*	Dec 71	43400	----

* Projected

TABLE 22

TEST HOURS IN THE TOTAL PROGRAM

Aircraft	Actual Total Development Test Hours	Optimal Total Development Test Hours	Actual Development Test Hrs After 1st Flight	Actual Total Testing After 1st Flight
XP-84	----	2400	----	2000
B-47	----	----	----	4415
F-89B	3600	2625	2600	4400
B-52	----	----	----	6298
F-100	----	4356	----	2498
F-3H	3578	7000	1100	1400
F-11A	7632	7500	4752	6927
F-101	2442	3400	350	3539
F-8	----	9000	----	6677
F-105A	----	7000	----	6102
KC-135	----	----	----	835
B-58	13765	14000	5428	6229
F-106	2850	2700	493	753
707	----	----	----	5010
T-2A	632	550	197	----
F-4	6044	6000	892	8204
RA-5C	8627	8613	1484	2967
T-38	4929	5000	856	----
880	2472	2096	376	----
OV-1	3509	3509	1344	----
X-15	5990	4786	----	----
A-6A	5650	5000	1174	----
E-2A	8225	8225	1428	----
727	----	----	----	1346
C-141	5476	5500	1058	----
B-70	13462	17000	85	----
XC-142	10317	8000	3104	----
F-111	26041	24000	5454	18706
OV-10A	2360	1450	1180	----
A-7	----	8724	----	4816
Gulfstream II	1989	2150	20	----
737	----	----	----	2208
C-5	7687	6000	52	1865
747	----	----	----	2476
SST	----	----	----	----

could represent either correction of problems discovered in flight or design philosophy (i.e., where a significant portion of the wind tunnel test program is planned in support of flight testing). Column 4 shows the total actual hours spent in wind tunnel testing after flight (it includes the data of Column 3). The reader's familiarty with the particular development programs will make these data more meaningful. Sometimes a substantial number of follow-on wind tunnel hours represents a very useful and extended aircraft life, with many modifications and adaptations to various engines and weapons (e.g., the B-52). Or, it could mean that problems were discovered during flight evaluation that necessitated an unusual amount of tunnel work after the first flight (e.g., the F-111).

Evaluation of the Optimal Wind Tunnel Program

The author had hoped to make some correlation of both the actual and optimal wind tunnel test program with the data provided by the evaluators in Questions 13-17, Appendix C. The respondent is asked in Question 13 to compare the development program being evaluated with others in his experience and to assess the level of technical difficulty for those technical areas amenable to investigation in the wind tunnel. Of the 26 aircraft evaluated, 6 were rated "high," 19 "medium," and 1 "low." The author observes that the aircraft that claim high levels of technical advancement in development did require more wind tunnel testing than their "medium" cousins. The technical advance which was rated "low" was a direct follow-on and experienced relatively little wind tunnel testing. However, within the range of "medium technical difficulty," the scatter is too great to make this categorical distinction worthwhile.

Question 14 asks for identification of constraints that influenced

the quantity and quality of the wind tunnel test program. Many respondents noted that pressures of money and time early in the program had a negative influence on the wind tunnel test program. It was often stated that there was insufficient time to take data, analyze it, and get it into the design. These data are further substantiated by the results of Question 25, Appendix B, which asks the same question without reference to a specific aircraft. Over 90% of those respondents stated that the wind tunnel programs are most constrained by too little time to properly use the wind tunnel and too little money devoted to this aspect of the development program in the early stages. The few other comments centered primarily around deficiencies in facility capability and problems of scheduling certain test facilities.

The evaluator is asked, in Question 15, Appendix C, to rate the success of the particular aircraft development program in meeting technical objectives in a timely and economical manner. Since a contractor is likely to define a successful program as one which results in the sale of many aircraft and makes a profit, the respondent is warned to ignore the ultimate usefulness or success of the system and evaluate only the development program. Of the aircraft evaluated, there were no poor development programs, no fair development programs, only 4 average programs, 16 good programs, and 4 very good programs. The author is aware that other evaluators outside this study have not been so kind in measuring the success of some of these aircraft in meeting performance objectives in a timely and economical manner. In particular, some RAND reports have provided objective comparisons of planned and obtained aircraft flight performance and development costs (21). It would appear that some of the evaluators either did not understand the question or were influenced to rate the success of their development program too optimistically. These ratings would perhaps have had more meaning if all respondents had been permitted to rate

the "success" of all development programs; however, time did not permit this adjustment in procedure after the final determination of the aircraft to be studied.

Because of the escalated and sometimes questionable rating of the development project success, coupled with scattered data on some aircraft wind tunnel test programs, the author has not found it possible to present a closed argument that the success of the development program and character of the wind tunnel program are always directly correlated. Some low technical risk aircraft developments have been performed in a short time period with relatively little wind tunnel testing, and have been successful. However, the author has observed that for most cases, the more successful development programs exhibit the characteristic of a substantial amount of wind tunnel testing early in the program. Also, the adjustment to an optimal program usually reflects the evaluators' desire for more wind tunnel testing earlier in the development cycle. The reader has probably observed from Tables 19 through 22 that the predominant trait of the optimal wind tunnel programs is a shifting of wind tunnel testing toward the early stages of the development cycle. In fact, many respondents reported that overall testing could have been reduced if this had been practiced. These opinions are seconded by the remainder of the respondents who answered Question 23, Appendix B. Without reference to a particular aircraft, this question hypothesizes that an aircraft development program could be improved and cost savings incurred if more effort were devoted to the wind tunnel test program earlier in the development cycle, particularly prior to design-freeze on the first flight vehicle. The responses are noted in Table 23.

The hypothesis has very good acceptance (by 84%) with 47% giving strong agreement; seven per cent reject the hypothesis. It is interesting to note that of the six individuals who differ with the large majority, five are from a particular group; i. e., ASD. The comments of these

TABLE 23

REPLIES TO HYPOTHESIS THAT MORE WIND TUNNEL TESTING PRIOR TO AIRCRAFT DESIGN-FREEZE WOULD IMPROVE THE DEVELOPMENT PROGRAM AND REDUCE DEVELOPMENT COSTS

Agency	Strongly Disagree	Disagree	No Opinion	Agree	Agree Strongly
Industry	0	1	3	7	15
ASD	1	4	2	6	5
Headquarters	0	0	1	2	4
AFSC Labs	0	0	1	7	2
AEDC	0	0	0	5	8
NASA	0	0	0	3	5
Other	0	0	1	1	1
Totals	1	5	8	31	40

individuals present the basic argument that there is a trade-off between optimization of the aerodynamic configuration (which can be done more efficiently in the wind tunnel) and accumulation of total system characteristics (which can be done only through flight tests). The single respondent who objected strongly stated:

> "It is a matter of degree, obviously. Pre-design freeze tests may or may not be applicable; you really get down to working the problem after the design freeze."

It appears that these few individuals would prefer to see the test emphasis shift toward more and earlier flight evaluation and less early tunnel testing. However, the overwhelming majority of respondents comment that <u>more and better wind tunnel testing early in the development cycle is the key to a successful development program</u>. It is appropriate to quote the comments of an industry respondent who has years of direct experience to back up his opinion:

> "This type of testing relates in a major way to the success or failure of the program. We spend orders of magnitude more

"money in tests to make a 'frozen' design work than we spend in tests directed to a true design optimization process."

The reader who is not aware of the importance of the wind tunnel data to aircraft development should find the answers to Question 16, Appendix C, of value. The expert evaluators were asked how strongly the wind tunnel test program influenced their particular aircraft development. Twenty-two of the 26 replied "very much," and the other 4 said "much." The following comments are typical:

-- The wind tunnel was essential to this program.

-- Wind tunnel data were the basis for the aerodynamic design of the basic airplane and high-lift system. In many cases, wind tunnel model lines were scaled up and used directly for the full scale airplane. Airloads data obtained in the wind tunnel were used for structural design. To a great extent the wind tunnel program paced the whole development program at times; particularly, prior to configuration freeze.

-- Aerodynamic design and airloads data were totally dependent on wind tunnel results.

-- This program was predicated on developing the configuration by wind tunnel tests to achieve the high cruise efficiency required. Both the external configuration and the internal ducting to the engine were developed by extensive testing.

The evaluator is next asked if he experienced any difficulty in obtaining certain data because of deficiencies in test facility capability (Question 17, Appendix C). Twenty of the 26 evaluators replied in the affirmative. However, this does not necessarily mean that adequate facility capability was unavailable; the author observes that sometimes less desirable facilities were used by choice (or dictated by time, money, availability, etc. constraints noted earlier). Facility deficiencies of the 1950's and 1960's are presumed to be of no particular interest to the reader and will be omitted. The deficiencies enumerated for modern development programs have been reported in more detail in response to another question and are discussed in the preceding Chapter.

Attention is now directed to Questions 9 and 21 in Appendix C. The author was attempting to derive results that would permit definition of an optimal test program by focusing on portions of the test program to be conducted in the various categories of facilities (as identified by charge rate). It became obvious from review of the answers and interviews with the evaluators that many respondents either could not find the data or had not made the analyses necessary to answer these questions. Furthermore, the instructions for calculating charge rates were not followed in all cases. Consequently, a presentation of the quantitative replies is considered useless. The author has observed one trend which may interest the reader. A comparison of the replies to Questions 9 and 21 will demonstrate the evaluator's intent in an optimal program to expand the test program to larger and more costly facilities, or to perform less testing in such facilities. Of the 22 aircraft evaluations which supplied data on these questions, 7 indicated that a much larger portion of the test load should be accomplished in the more sophisticated facilities; 2 are directed toward a reduction of testing in such facilities, and 13 imply no change in this regard.

It has been hypothesized that better use of the wind tunnel during aircraft development would result in such benefits as reduced cost, better performance, etc. Proof of the hypothesis is attempted in Question 23, Appendix C, through evaluation of the specific aircraft programs. The evaluator is asked if certain benefits would (in his opinion) have been derived from implementation of his optimal program. Recall that the optimal wind tunnel test program has the predominant traits that more wind tunnel testing is accomplished early in the development and time is permitted for testing and analysis of data: also, there is some shift toward an increase in testing in the larger and more sophisticated wind tunnels. The results are shown in Table 24.

TABLE 24

IMPROVEMENTS IN THE DEVELOPMENT PROGRAM
EXPECTED FROM BETTER USE OF TEST FACILITIES

Question	Yes	No
Do you believe that implementation of your hypothetical test program would have resulted in:		
Less overall development cost?	17	6
Superior system performance?	17	6
Shorter time to system demonstration?	8	15
Less flight testing required?	19	4

At least one of the four benefits was claimed for each of the 23 aircraft on which the data were furnished. Most experts predict that the optimal test program would have resulted in less overall development costs, superior performance and less flight testing. About one-third would have expected a shorter time period prior to system demonstration. These results are most significant to this study. The respondents explained these answers in interview with the author based upon specific problems associated with the aircraft development program being reviewed. The reduction in development cost was primarily expected because certain design deficiencies would not have been built into the aircraft; the respondent, therefore, expected less flight testing and follow-on wind tunnel testing to resolve these deficiencies. Respondents pointed out that flight testing is at least an order of magnitude more costly than wind tunnel testing, and is not nearly so effective and precise for most required aerodynamic data. Superior system performance was expected because of a more optimized design based on wind tunnel tests. Respondents observed that too often performance deficiencies discovered in flight are accepted because corrections at that time would be prohibitively

expensive. Most respondents expected implementation of the optimal test program to result in a longer time period for development prior to flight. However, many respondents stated in interview that they expect the total time to put an aircraft in inventory will not be so affected because of reduced time spent in correcting mistakes.

It is desirable to find specific deficiencies revealed in the flight evaluation of the aircraft under review which the respondent feels his optimal test program might have minimized or prevented; the point is addressed in Question 24, Appendix C. Four aircraft had no such deficiencies. From the 20 positive replies, a few comments are noted for the benefit of the reader.

-- Flaps showed severe separation from tracks which were inadequately simulated on models. Clean drag was about 13 counts higher than necessary because of poor wing-fuselage fairing, but we learned too late. Reynolds number effects on airloads were mispredicted.

-- Engine-airframe integration and high angle-of-attack stability and control.

-- Deficiencies in the control system would have been exposed with tunnel hinge moment data.

-- Stall characteristics. More tunnel time at an earlier date could have precluded some flight tests and later wind tunnel tests.

-- Changes in wing camber made after flight could have been determined in earlier wind tunnel tests.

-- Buffet surveys in the wind tunnel would have resulted in aerodynamic fix and better performance.

-- Horizontal tail hinge line was relocated as a result of flight testing. Leading edge slat was found unnecessary as a result of flight testing.

-- Tail hinge moment problem, rudder size for spin recovery, and flap buffet.

One respondent who answered "no" made this interesting comment:

> -- However, much redesign and schedule slippage pressure could have been avoided if the optimal wind tunnel test program could have been followed. Obviously, many millions of dollars of cost could have been saved as well.

This same theme is pursued in Question 24, Appendix B, for the remainder of the respondents. It is speculated that some deficiencies found in the flight evaluation phase might have been prevented with a more thorough facility test program, but with perhaps attendant increases in time and cost of that phase. The respondent is asked to discuss the results of his experiences on the relative costs of facility testing versus correction of design deficiencies, and express any ideas he may have to optimize the trade-off. Most of the respondents answered this question with general comments that more early wind tunnel testing was desirable, that wind tunnel testing was much cheaper and desirable for certain data, etc.; i.e., the same arguments that have already been presented. A few respondents attempted to quantify their answers; two of these comments are noted below.

From an ASD respondent:

> I believe that 80 to 90 per cent of the cost required to fix up a new aircraft after flight tests have started could be saved by running more wind tunnel tests before final design freeze. This is based on our recent F-111 experience. This is probably true for any subsonic-supersonic configuration where design compromises are often required for efficient supersonic flight.

From an AFSC Laboratory respondent:

> The cost of "fixing the fleet" is several orders of magnitude greater than an adequate test program. Based on a risk analysis study, as much as one-half the "get well" costs should be spent on a test program.

A few respondents have challenged the author to <u>prove</u> that certain deficiencies found on particular aircraft could have been found in wind tunnel tests and prevented. Unfortunately, it is impossible to "prove" that testing which was not accomplished would have resulted in any specific results. However, the overwhelming agreement and testimony of many of this nation's most knowledgeable experts should convince the skeptic that the wind tunnel test programs are not in proper balance.

The argument presented here is not an either/or case; i.e., flight testing or facility testing. Certainly there is no claim that all problems can be found in the wind tunnel. Certain interface problems and other unknowns or unexpected problems will often appear in flight evaluation. Several respondents (primarily from government circles) have observed that the "major problems" always occur in flight tests. These are all "truths"; they do not, however, lead to the conclusion that one should push for early prototype aircraft at the sacrifice of an adequate facility test program. Certainly the "major problems" are discovered in flight; discovery at this development stage makes them major problems. Corrections made in the wind tunnel are inexpensive and never make the headlines. The message that comes from the large majority of expert respondents is this:

> The present balance between preventing problems and solving problems is far from adequate. Industry's and government's backlog of experience is highly oriented toward fixing problems which may result from insufficient testing and development. This is being forced by reluctance to commit appropriate funds at a rate sufficient to support an optimal program plan. Facility testing cannot solve all the problems; however, it can greatly reduce the possibility of problems.

Functions of the Wind Tunnel in a Development Program

The wind tunnel is used to perform a variety of functions in the aircraft development program. The priority attached to these functions has some influence on the use of the wind tunnel and its contributions to development. It is interesting to observe how different groups of respondents rate the purposes for testing in the wind tunnel. Question 27, Appendix B, seeks to determine the respondents' ranking of importance of functions which denote categories of use of the wind tunnel in the development program. The results are shown in Table 25. The functions are defined as follows:

a. Verify the design hypotheses; i.e., assure that theory and past experiences have been applied correctly and produce expected results.

b. Generate new design information and improvement in the design concept; i.e., produce new technology to be applied to the system.

c. Expose difficulties which may have been overlooked; i.e., look for undefined and unexpected problems.

Overall, the respondents choose category "a" as first choice preference, "c" as second choice preference, and "b" as third choice preference. The NASA respondents are more inclined to argue the trend. This response might be expected because of their strong research orientation; i.e., they could be expected to rate option "b" higher than others. Some readers have probably already observed that a different conclusion may be deducted from these results. If one looks only at first choices, option "b" ranks second instead of third. Note the solidarity of the ASD response. Some ASD respondents commented that option "b" should not even be included in a development program; i.e., they feel that production of new technology is not part of systems development. Other

groups of respondents do not tend to feel so strongly as those from ASD.

TABLE 25

RESPONDENTS' PRIORITY FOR FUNCTIONS OF WIND TUNNEL TESTING

Agency	Number of 1st Choices			Number of 2nd Choices			Number of 3rd Choices			No Answer
	a	b	c	a	b	c	a	b	c	
Industry	11	7	3	7	5	9	3	9	9	7
ASD	14	3	1	3	1	14	1	14	3	0
Hdqtrs.	4	0	2	1	3	2	1	3	2	1
AFSC Labs	4	2	4	4	1	5	2	7	1	0
AEDC	7	2	1	2	1	7	1	7	2	3
NASA	1	3	3	4	2	1	2	2	3	1
Other	0	1	1	1	1	0	1	0	1	1
Totals	41	18	15	22	14	38	11	42	21	13

The results of Table 25 do not include the responses of the evaluators of the specific aircraft programs. These respondents were asked in Question 25, Appendix C, to designate the relative importance of the three categories, both in the aircraft development program being evaluated and in the optimal development program. It was intended to determine how the optimal use of the wind tunnel differs from the actual use. The results are shown in Table 26.

Although the overall trend of the results in Table 26 is the same as that exhibited in Table 25, the move toward an optimal test program indicates a slightly different emphasis. In Table 26, strong stratification of functional emphasis is noted for the actual programs evaluated (similar to that demonstrated by the ASD responses in Table 25). However, a moderating trend, with more emphasis on generation of new design information, is observed in the categories of the optimal programs. A few respondents have added a fourth wind tunnel test function to the

list; i.e., support of flight test programs. However, most ranked it fourth in priority.

TABLE 26

COMPARISON OF WIND TUNNEL FUNCTIONAL PRIORITIES FOR ACTUAL AND OPTIMAL WIND TUNNEL TEST PROGRAMS

	No. of First Choices			No. of Second Choices			No. of Third Choices		
	a	b	c	a	b	c	a	b	c
Actual Programs Evaluated	23	6	1	3	6	21	4	18	8
Optimal Programs	16	8	6	8	8	14	6	14	10

The only safe conclusion to be drawn from these data is that there are a variety of opinions regarding the priority of the functions of wind tunnel testing. However, there may be some significance to the observation that the ASD reponses are consistent with the estimates of priorities in the actual development programs. This could mean that ASD has exerted a significant influence on the type and timing of wind tunnel testing in the actual development programs. If this be the case, it should be observed that the recommended optimal test programs reflect some change in emphasis; particularly, there is more recognition of the wind tunnel's ability to generate new design information and produce improvements in design concepts during development.

Design of an Optimal Wind Tunnel Program

There are many occasions when the aerospace engineer or manager has need for an estimating procedure which predicts the magnitude and type of wind tunnel test program which would be appropriate for a proposed new aircraft system. Such occasions include the potential contractor's estimate for his proposal, the government evaluator's review and comparison of contractor's proposals, the planner's estimate of future development program cost and time, or perhaps the wind tunnel operator's estimate of future workload. The development of the new wind tunnel program usually involves a lengthy review and evaluation of past wind tunnel programs to provide a basis for extrapolation. It is the purpose of the following analyses to develop a method to permit an estimate of an optimal wind tunnel test program with limited knowledge about the future aircraft program and without the review of past programs. Such an estimating procedure should serve as a means for determining quick and approximate wind tunnel programs and should provide a basis on which to build more detailed test programs.

It is common to observe in the literature trend lines which show wind tunnel test hours on aircraft development programs as a function of development or flight year (22). The author has observed that many of the aerospace engineers associated with wind tunnel programs have their own private collection of such data. Depending upon the time frame of the data and the aircraft selected for inclusion, the originator of such a plot can demonstrate various trends of his own choosing. Several things about this practice have concerned the author. First, some of the data points on such plots usually represent very poorly designed wind tunnel test programs; i.e., data points which represent either too little or too much testing are used as a basis for extrapolation. Then, too, the author has observed that sometimes the data are not consistent in that

they may represent either the quantity of testing at first flight or total wind tunnel testing(which often includes many modification and retrofit programs). A third concern is the wide scatter in the data, which is evident even when one tries to camouflage the dispersion by starting with very old data and congregating the modern data on a semi-log plot. Some of these curves, which are sharply rising exponentials, appear to provide a poor basis for extrapolation. All the trends demonstrate some increase in amount of testing with increase in calendar years. The need for some quick and simple estimating procedure is demonstrated by the fact that such calendar year-test hour trend lines are used for making predictions; i.e., it is insinuated that a proposed aircraft development program should have a certain quantity of testing based upon extrapolation of such curves. The method for estimating the magnitude of a wind tunnel program to be developed here will, hopefully, provide some correction of the faults noted above.

There is, indeed, some positive correlation between wind tunnel test hours and calendar year of first flight. However, if one will closely observe the characteristics of the aircraft whose test programs have been reported, he will be able to make a few generalizations about the data. For a given time period, those aircraft that have had the most testing in a wind tunnel are usually either faster, bigger, heavier, or have more thrust than those which have had less testing. Such observations led the author to conclude that multiple predictors might provide a better estimate of wind tunnel test hours than calendar year alone. One would expect the systems to require more testing with increasing time as they become more complex and push technical limits more closely. However, one must acknowledge that accumulated technology should counter this trend and tend to reduce the slope of the curve as time increases. Thus, some of the physical and performance characteristics of the aircraft will be added to the time factor in a multiple regression analysis in an attempt

to provide a better correlation.

The idea of the optimal test program was originated to eliminate inadequate test programs from the basic data. The "experts," who know the most about the particular aircraft development program and the usefulness of the data, have carefully reviewed the original test programs and made the adjustments which they believe would have made them more effective. The characteristics of the optimal test program have already been observed. Certainly, more individual evaluations on each aircraft test program optimization would have been desirable to reduce the influence of any one man's opinion; as noted, this was not usually possible. The author had also hoped to include more aircraft in his survey; for reasons stated earlier, this, too, was impossible.

A standard multiple regression computer program was used to test the ability of a number of independent variables to predict optimal test hours at first flight. The computer program included a sub-routine which permitted expression of non-linear variables in linear form. The author took advantage of this program to test various logarithmic and natural combinations of all variables. The various predicting equations were evaluated by observation of the multiple correlation coefficient and a study of the individual residuals (i.e., optimal test hours minus predicted test hours). The significance of the predictors (in various combinations) was determined with an F-test. The reader is directed to Appendix E for a more complete description of the regression program, mathematical expressions, and results that are not detailed in the text.

One must exercise care in the interpretation of a correlation coefficient as a measure of the linear relationship between variables. It is simply a mathematical interpretation and is completely devoid of any cause or effect implications. One must use his familiarity with the variables and the field of application to determine if the variables have any effect on each other. The author has already expressed his concern

over the use of calendar year as a single predictor. However, it is the author's opinion that speed, weight and thrust should rise and fall in concert with test hours. Certainly the faster aircraft require more testing, simply because they must be evaluated in several speed regimes and in several types of tunnels. As aircraft weight increases, the size and cost of the aircraft usually increases and interest in reducing risk increases. As total thrust increases, either aircraft size or performance (or both) increase; either implies more testing in development. It is suggested that calendar year is only indirectly associated with quantity of testing through its correlation with these and/or other variables.

The first case tried included 33 aircraft. These are all that are listed in Table 18 except the X-15 and XC-142, which the author felt were too unique to be compatible with the other data. Four regression analyses were performed; i.e., both dependent and independent variables were used in both logarithmic and natural (raw) format. For example, one combination would be:

Log optimal hours and raw predictors.

The "raw data" are the natural numbers. The reader will observe several possible "curve" shapes from these expressions. The predictors which were tested were:

Weight
Thrust
Speed
Calendar Year of First Flight
Categories:
  Combat/Non-combat
  Fighter/Bomber
  Miscellaneous/Cargo

The first three predictors are as described in Table 18. The "categories" can be considered additional independent variables. It may be observed in Appendix E that none of the trials with logarithmic expressions gave as good correlation as the one with the raw data.

Calendar year of first flight was used as a single predictor to give a correlation coefficient (R) of 0.506. A combination of weight, thrust and speed gave a multiple correlation coefficient of 0.918 (1.000 is perfect correlation). Observation of the F-ratios shows that neither year nor the categories add to the significance of the prediction. Unfortunately, a close examination of the results showed that the correlation statistics were somewhat misleading because one aircraft (the SST) had such a large influence on the data.

The decision was made to eliminate from consideration a number of aircraft for various reasons and try another regression. The older aircraft were omitted (the F-84, F-89, and B-47 have flight dates prior to 1950); the three propeller aircraft were omitted (the OV-1, E-2A, and OV-10A); the smaller trainer aircraft were eliminated (T-2A and T-38); the F-106, KC-135, and 707 have reduced development cycles and were omitted (the F-106 closely followed the F-102, and the 707 followed the KC-135, which itself followed the Boeing 367-80); the SST was omitted both because of its dominance over the data and its irregular development cycle (three incomplete aerodynamic configuration developments); and the F-111 was eliminated because of its variable-sweep wing. The variable-sweep wing requires more wind tunnel testing because of the many configurations; i.e., essentially, more than one aircraft is being developed.

The 20 surviving aircraft were used in a multiple regression similar to the preceding case. This time, the categories were dropped as independent variables. Again the raw dependent and independent variables showed better correlation than the various logarithmic combinations. Thrust/weight ratio was tried as an additional predictor (independent variable) to see if it would aid the raw-raw correlations. It may be observed from the tabulated data in Appendix E that neither thrust/weight ratio nor calendar year add significantly to any of the better combinations of

predictors. For this case, calendar year of first flight has a correlation coefficient of 0.317 when used alone. The better predictors and their multiple correlation coefficients are:

Weight, thrust, speed	:	$R = 0.856$
Weight, thrust	:	$R = 0.853$
Thrust	:	$R = 0.733$

Two other combinations were attempted. Seven fighter aircraft made up one group and 10 of the larger post-1960 aircraft composed the other group. Unfortunately, there were too few fighter aircraft for a meaningful multiple regression. For the 10 more recent aircraft, the SST became even more dominant in the statistical anlysis. The author chose not to record either of these cases in Appendix E. However, it is suspected that if enough aircraft data could be collected to permit individual regressions for each category of aircraft, the extrapolation outside the range of data would be improved.

Based upon these analyses, the author prefers the following equation as a predictor of optimal test hours at first flight:

$$H = 2100 + 0.118\,T - 0.0181\,W + 1.17\,S$$

where:

H = optimal test hours at first flight

T = maximum total aircraft sea-level static thrust (pounds), with after-burner, if installed

W = takeoff gross weight (pounds)

S = maximum speed at best altitude (miles per hours).

This prediction equation has a reasonably high multiple correlation coefficient for the 20 subject aircraft ($R = 0.856$); the constant is not unreasonably large; there are three predictors which intuitively correlate with the dependent variable; the residuals do not have any highly irregular pattern; and it appears to predict adequately outside its range

of variables. It may be observed in Appendix E that the predicting equation preferred by the author does not give the largest F-ratio. However, the rationale for this choice is further explained in the Appendix. The reader will observe that other predicting equations based on different variables and combination of variables are also given in Appendix E. These will prove useful if one is not provided sufficient predictors to use the preferred equation.

The reader may share the author's earlier concern that the "weight" term in the preferred predicting equation is negative, although it is shown in Appendix E that weight used as a single predictor is positively correlated with optimal test hours. It can be illustrated, by working out several examples, that thrust is the significant determinant of test hours for most of the aircraft; further, there is a very good correlation between thrust and weight (this information is not presented). It was observed that the "weight" term was negative in all the equations which included the "thrust" term, both in Appendix E and in the many examples not included in the presented information. The author has concluded that there is no significance to the negative "weight" term; this is simply the solution to the regression equation for the data presented. It does not mean that higher weight aircraft require less testing; it does mean that weight, in concert with the other predictors in the equation, best describes the optimal test programs for the given aircraft in the manner illustrated.

The test hours at first flight, as predicted by the preferred equation, are shown for the 20 aircraft in Table 27. Also shown are the residuals; i. e., optimal test hours at first flight minus the predicted optimal. Fairly large residuals were expected because the data reflect the test philosophies of both the evaluators and the aircraft companies. Historically, some companies perform more testing than others. The predicted test hours represent an "averaged" value of expert opinion and test philosophy. For example, when two aircraft are as close in performance, size and time period as the C-5A and 747, yet are subject to such widely divergent

TABLE 27

PREDICTED TEST HOURS AT FIRST FLIGHT
20 AIRCRAFT

Aircraft	Predicted Test Hours at First Flight	Residual
F-11A	3942	58
Gulfstream II	4456	- 2306
A-6A	3967	1033
F-105	5730	1270
F-101	6066	- 3066
F-3H	3922	3078
F-4	6872	871
RA-5C	6403	726
880	4754	- 2685
B-70	16586	414
F-100	3672	684
C-141	6910	- 1411
C-5A	8908	- 2908
A-7	3525	383
F-8	4648	- 248
B-58	8173	- 173
B-52	4582	617
727	4832	- 757
737	4060	- 2640
747	10479	3521

Note: Predicted Test Hours = function (weight, thrust, speed).

estimates of optimal test hours, large residuals are assured. Note that the regression equation brings the C-5A test program more in line with its actual program and reduces the optimal program for the 747. The reader who is familiar with the individual aircraft development programs can explain many of the variations between the actual and predicted test hours. For example, consider the F-101, whose optimal test hours at first flight are over-predicted by the regression equation by a factor of two. One must account for the fact that the F-101 was the successor to the XF-88, an experimental aircraft, and therefore had advantage of a substantial quantity of data on the basic aerodynamic configuration. The predicted test program is in keeping with a developmental program that starts without such a substantial backlog of data. On the other hand, the F-3H is under-predicted by a substantial margin. On Table 21 it is observed that this particular evaluator almost tripled "actual test hours" for his "optimal test hours" estimate; this is by far the largest per cent change in any program evaluated. The "averaged" estimate, as predicted by the regression equation, shows that the optimal test program should have a substantial increase, but not so large.

The regression equation based on the 20 aircraft has also been used to predict the optimal test hours at first flight for those aircraft omitted from the regression (the results are shown in Table 28). The older programs fit nicely, but the propeller aircraft are not predicted so well. Those programs which were identified as close follow-ons to others (F-106, KC-135, and 707) are reasonably predicted, if one adds cumulative hours from preceding development programs. The equation is not recommended for vertical or short-takeoff aircraft; neither does it predict rocket driven aircraft test programs.

The regression equation predicts "averaged" or "standard" test programs; one must adjust the prediction to fit the needs of the particular aircraft. The author has considered the predictions for the F-111

TABLE 28

PREDICTED TEST HOURS AT FIRST FLIGHT
OUTSIDE THE REGRESSION DATA

Aircraft	Predicted Test Hours at First Flight	Residual
XP-84	3100	- 700
F-89	3770	- 1145
B-47	2870	- 20
OV-1	2825	- 660
E-2A	3910	2375
OV-10A	2620	- 1720
T-2A	2945	- 1395
T-38	3800	200
F-106	5270	- 2770
KC-135	3880	- 3280
707	4240	- 2590
F-111	7000	13040
SST	25000	18400
XC-142	5000	3000
X-15	13775	- 8989

Note: Predicted Test Hours = function (weight, thrust, speed).

and SST in Table 28 and reviewed the test programs for more modern military aircraft not included in this study (F-14, F-15 and B-1). Some corrections are suggested for use of the regression equation. Aircraft that incorporate novel aerodynamic design which is of a "pioneering" nature should have an increase in test hours by a factor of about 1.5. The same is true for aircraft which extend the performance envelope beyond standard technology, or strive for operational performance at several extreme operating conditions. Any of these events should increase the amount of testing required. The swing-wing aircraft "predicted test program" should be adjusted upward by a factor of two (after the corrections noted above are made). Of course, these adjustment factors must be moderated as certain technologies become more standard.

There are additional guidelines for establishing an optimal test program which can be derived from the available data. Tables 29 and 30 provide estimates for the subdivision of optimal wind tunnel test hours for transonic and supersonic aircraft by wind tunnel type (i.e., subsonic, transonic, and supersonic). Spin testing is included in subsonic testing. These data are based on the optimal test program as predicted by the evaluator where the information is available; otherwise, they are based on the actual development program or the actual total test program. One may find estimates for transonic aircraft in Table 29 and for supersonic aircraft in Table 30. Of course, the suggested test program should be further adjusted to reflect emphasis in test regimes where problems are known or suspected.

Table 31 permits one to phase the test program with time. As in all these techniques for prediction, the average opinion is suggested. However, it is observed that the overall average for all 24 aircraft and the average for the various categories shows little variation. The optimal test hours at first flight, as predicted by the regression equation, represent

TABLE 29

SUBDIVISION OF TEST PROGRAMS BY WIND TUNNEL TYPE: TRANSONIC AIRCRAFT

Aircraft	% Subsonic Testing	% Transonic Testing
Fighter/Attack		
F-100	35	65
F-3H	36	64
F-11A	67	33
F-8	39	61
A-6A	74	26
A-7	53	47
Average	51	49
Bomber		
B-52	77	23 *
Large Commercial		
707	52	48 *
880	72	28
727	57	43 *
737	41	59 *
747	53	47 *
Average	55	45 *
Military Cargo		
C-141	63	37
C-5	58	42
Average	60	40
Small Commercial		
Gulfstream II	84	16
Trainer		
T-38	70	30

Note: These data are based on the optimal development test program except as designated.

* Based on total amount of testing.

Supersonic testing for the F-100, F-3H, F-11A and F-8 is included in transonic testing.

TABLE 30

SUBDIVISION OF TEST PROGRAMS BY WIND TUNNEL TYPE: SUPERSONIC AIRCRAFT

Aircraft	% Subsonic Testing	% Transonic Testing	% Supersonic Testing
Fighter/Attack			
F-101	35	35	30
F-105	43	31	26
F-106	30	35	35
F-4	25	42	33
RA-5C	41	15	44 *
F-111	19	51	30
Average	32	35	33
Bomber			
B-58	14	29	57
B-70	23	24	53
Average	19	26	55
SST	23	31	46 o
X-15	21	15	64

NOTE: These data are based on the optimal development test program except as designated.

* Based on the actual development test program.

o Based on total testing performed as of end of CY 1970.

TABLE 31

TIMING OF THE TEST PROGRAM

Aircraft	% Testing at Contract Award	% Testing at Design Freeze	% Testing at First Flight
Fighter/Attack			
F-100	6	81	100
F-3H	21	64	100
F-11A	20	47	53
F-101	35	68	88
F-8	9	36	49
F-105	29	100	100
F-106	0	78	92
F-4	17	67	100
RA-5C	26	53	83
A-6A	12	96	100
F-111	21	53	83
A-7	19	42	45
Average	20	65	83
Larger Aircraft			
B-58	0	43	57
B-70	20	76	100
880	0	100	100
Gulfstream II	7	93	100
C-141	27	100	100
C-5	42	100	100
Average	16	85	93
Propeller Aircraft			
OV-1	7	57	62
E-2A	12	64	76
XC-142	13	87	100
OV-10	38	55	62
Average	18	66	75
X-15	0	83	100
T-38	12	60	80
AVERAGE BASED ON ALL 24 AIRCRAFT	17	71	85

85% of the testing recommended for the total development program; only 15% of the wind tunnel test program is reserved for support of flight testing. The regression equation should then be increased by a factor of 1.18 to reflect the total development facility test program.

One must exercise great care in the use of these techniques for predicting optimal test programs. At best, they should be considered base-line estimates to which adjustments can be applied. It has already been observed that every aircraft development program is a unique case. One who uses these techniques should be familiar with the particular requirements of his program. Individual and company test philosophy will continue to deviate from the "average"; time and dollar constraints will probably also continue to affect test programs. Other types of deviation from the "average" wind tunnel program are suggested by the B-1 development program, where a very long pre-contract study program has shifted the test program completely out of phase and magnitude with these estimates.

However, these predictors should serve several useful purposes. For those developing a new detailed test plan, they may serve as a point of departure. They should provide a means of measurement for evaluation of proposed test programs. The planners who attempt to predict facility workloads for future aircraft should find the techniques useful. The predictors presented here can and should be improved. The fact that good correlation was obtained for so large an assortment of aircraft encourages one to believe that predictors within categories would be even better. Perhaps predictors within given speed ranges and with different independent variables would show even better correlation. However, the effort required is beyond the limitations of this study.

The author cautions against the use of independent variables (or predictors) that do not intuitively suggest a relationship with the dependent

variable. A further note of caution should be exercised against the use of complicated and higher order mathematical expressions which also elude intuitive interpretation. Such expressions can be forced to fit the scatter in the data to give very good correlation, but may be completely worthless as an indication of trend or for data outside the range of variables. Even now, one must be careful about the use of the regression equation outside the range of the data on which it was based. Particularly, it appears that the suggested techniques may overpredict the test needs of a very large, high-supersonic aircraft with swing-wings and other advanced aerodynamic features.

Test Program Costs

As reported earlier, the data on costs of testing were sketchy and subject to various interpretations. However, it is desirable for planning purposes to have some idea of probable test costs on future aircraft development programs.

The author has completed the cost estimates for several of the more recent and major military aircraft testing programs by using certain data furnished in other completed estimates and his own knowledge of wind tunnel test costs. Based upon eleven aircraft development programs and 1970 cost estimates, it appears that the total test cost per test hour is between \$1800 and \$3100. However, eight of the estimates were between \$2000 and \$2500 per test hour. These test costs include aerodynamic models, facility usage or operation (including cost of government facilities), data collection and analysis, and special facility construction or modification at the contractor's facility, which was special for this test. This last item did not affect any of the results.

Since the optimal test program leans toward greater use of the more sophisticated facilities, it is suggested that a figure of about \$2500 per

test hour be used for estimating the total cost of wind tunnel testing for major aircraft development programs. The smaller, low-performance aircraft development programs can probably use simple models and more inexpensive facilities, and should cost perhaps one-half the above estimate. These estimates must change from a 1970 cost-base to account for future economic trends. "Free" testing will not change the overall cost of the test program, but will be reflected in charges to the development program.

Summary of Test Program Predictors

The recommended predicting procedures for an optimal wind tunnel test program are summarized to make them more accessible and to clarify their usage. The following equation is suggested to predict the total wind tunnel test hours in a normal aircraft development program:

$$T.\,H. = 2470 + 0.139\,T - 0.0213\,W + 1.38\,S$$

where:

T. H. = total development test hours in a wind tunnel

T = total maximum aircraft sea-level static thrust (pounds), with afterburner, if installed:

W = takeoff gross weight (pounds);

S = maximum speed at best altitude (miles per hour).

The predicted test program should be increased by a factor of about 1.5 for aircraft which incorporate novel aerodynamic design of a pioneering nature, aircraft which are expected to operate at several extreme operating conditions, and aircraft which extend the performance envelope beyond standard technology. If the aircraft is of a variable-sweep wing design, the predicted test program should be increased by a factor of two (after the above correction is made).

The predicted test hours should be phased in the development pro-

gram as noted:

15% prior to contract award,

70% prior to design freeze,

85% prior to first flight.

Subdivision of the optimal wind tunnel test program by tunnel type (i. e., subsonic, transonic, and supersonic) is possible with the aid of Tables 29 and 30. Note that these test hours do not include development of the propulsion system.

An estimate of testing costs can be obtained for modern advanced aircraft from the predicted optimal test hours and a rate of $2500 per test hour. These charges include wind tunnel costs (including government facility charges), model costs, and contractor personnel to collect and analyze the data. These estimates are based on 1970 dollars. Smaller, low-performance aircraft should cost only about one-half this amount.

The reader should observe the restrictions noted earlier in this chapter before applying these techniques.

APPENDIX A

LIST OF RESPONDENTS TO QUESTIONNAIRES

APPENDIX A

LIST OF RESPONDENTS TO QUESTIONNAIRES

N A M E	RANK	T I T L E
AERONAUTICAL SYSTEMS DIVISION		
Bellis, Benjamin N.	Brig. Gen.	F-15 SPD
Boykin, J. Arthur, Jr.	PL-313	Tech. Dir./Weapon Syst.
Daley, Robert P.	Col.	Dep. for Eng.
Esposito, Alfred L.	Brig. Gen.	Dep. for Syst. Mgmt.
Greenlay, Robert R.	Col.	Dir. Drone Mgmt.
Guthrie, Joseph A., Jr.	Col.	Asst. Subsyst. Mgmt., C-5 SPO
Haviland, George	Col.	Dir., Airframe Subsyst. Eng. Dir.
Hildebrandt, James E.	Col	A-X SPD
Klepinger, Richard H.	GS-15	Chief, Aeromech. Div., Dir. Airframe Subsyst. Eng.
Lengnick, R. H.	Col.	F-111 Dep. SPD
Martin, Reese S.	Col	Dir. Test & Deployment, Dep. for F-111
Miller, William B.	GS-16	Tech. Dir., Airframe Subsyst. Eng.
Orazio, Fred D., Sr.	PL-313	Scientific Dir., Dep. for Dev. Planning
Rall, F. T., Jr.	GS-15	F-15 Chief Eng.
Rushworth, Robert A.	Col.	Commander 4950^{th} Test Wing (Technical)
Sea, Austin L.	GS-16	Syst. Eng. Dir., Dep. for B-1
Stringer, Elbert M.	Col.	F-5E SPD
Tremaine, Stanley A.	GS-15	Supervisory General Eng.
Trenholm, John B., Jr.	GS-15	Tech. Dir., B-1 SPO
AERO PROPULSION LABORATORY (A.F.)		
Dunnam, Marc P.	PL-313	Dep. Dir. APL
One other who wishes to remain anonymous		

NAME	RANK	TITLE
ARNOLD ENGINEERING DEVELOPMENT CENTER		
Camp, C.	GS-15	Chief, Op. Analy. Off., Dir. of Test
Croy, Roy R., Jr.	Col.	Vice Commander
Eastman, Donald R.	PL-313	Chief Scientist
Furlong, G. Chester	GS-15	Tech. Adv. to Dir. of Test
Glaser, Leonard T.	GS-15	Chief, Plans, Programs & Policy Off.
Henry, Joseph R.	Col.	Dir. of Test
Maynard, Harry L.	Col.	Dir. of Technology
* Hensel, R. W.		Dir. of Operations
* Pindzola, Michael		Chief, Propulsion Wind Tunnel (PWT)
* Potter, J. Leith		Chief, Aerospace Div., VKF
* Schueler, C. J.		Chief, Aerodynamics Div., VKF
* Whitfield, Jack D.		Chief, von Karman Gas Dynamics Fac. (VKF)
* Wimbrow, William R.		Mgr., Pilot Tunnels Br., PWT
FLIGHT DYNAMICS LABORATORY (A.F.)		
Antonatos, Philip P.	GS-16	Chief Flight Mech. Div.
Harney, Donald J.	GS-15	Asst. for Experimentation
Hoener, Richard F.	GS-15	Asst. for Res. & Tech., Struc. Div.
Lindenbaum, Bernard	GS-15	Dep. for Stud. & Analy., V/STOL Tech. Div.
Magrath, Howard A.	GS-16	Dir., Vehicle Dynamics Div.
Scolatti, Charles A.	Col.	Chief, Flight Control Div.
Westbrook, Charles B.	GS-15	Chief, Control Criteria Br.
Zonars, Demetrius	PL-313	Chief Scientist

* Members of ARO, Inc., Operating Contractor at AEDC

NAME	RANK	TITLE
HEADQUARTERS AIR FORCE SYSTEMS COMMAND		
Peters, John D.	Brig. Gen.	Dir. of Civil Eng.
Roe, Frank L., Jr.	GS-16	Tech. Dir. of Test. DCS/Operations
Slay, Alton D.	Brig. Gen.	DCS/Operations
Wimer, Arthur G., Jr.	PL-313	Chief Scientist
HEADQUARTERS U. S. AIR FORCE		
Goldsworthy, Harry E.	Lt. Gen.	DCS/Systems and Logistics
Hargis, Calvin B., Jr.	PL-313	Dep. for Development, SAF R & D
Kucheman, H. B., Jr.	Maj. Gen.	Asst. DCS/R & D
NASA		
Baals, Donald D.	GS-16	Asst. Ch., High-Speed Aircraft Div. (LRC)
Becker, John V.		Ch., Hypersonic Vehicles Div. (LRC)
Boatwright, William B.	GS-15	Head, Adv. Facilities Res. Sect. (LRC)
Boswinkle, Robert W., Jr.	GS-16	Tech. Asst. to Dir. for Aero (LRC)
Howell, R.	GS-15	Head, High Temp. Str. Br. (LRC)
Jones, J. Lloyd		Research Asst. to Director (ARC)
Kelly, Mark W.	GS-15	Chief, Lg. Scale Aero. Br. (ARC)
Lundin, Bruce T.		Director, Lewis Research Center
THE BOEING COMPANY		
Gray, William L.		Staff Eng., Off. V.P. for R & D
Miller, Douglas S.		Aero. Configuration Unit Ch.
Ruffner, B. F.		Dir., Product Res.
Wimpress, J. K.		Mgr., Airplane Tech., Aerospace Gp.

N A M E	RANK	T I T L E
FAIRCHILD HILLER CORPORATION		
Kremowski, John E.		A-X Stab. & Cont. Gp. Leader
Matarazzo, Aniello		Sr. Syst. Eng. -- Aero.
Neuburger, H. Roy		Aero. Staff Eng.
Rosenthal, Gordon		Chief of Aerodynamics
Rubin, Arnold		A-X Wind Tunnel Test Coordinator
Torrillo, Dominick T.		Principal Aero Systems Eng.
Williamson, John M.		Chief Eng.
GENERAL DYNAMICS CORPORATION		
Craig, R. E.		Design Specialist
Heinemann, E. H.		Vice President
MacCarthy, W. T.		Eng. Mgr., Wind Tunnels
Madsen, A. P.		Chief, Aerospace Model Testing
Maske, E. B.		Program Director, TIP
Piszkin, Stanley T.		Design Specialist
Wild, John M.		Dir. of Eng. Technologies
GRUMMAN AEROSPACE CORPORATION		
Byars, L. T.		Project Aerodynamicist
Cuffe, Alfred G.		Project Aerodynamicist
Curtis, Edward J.		F-14 Drag & Performance Unit Ldr.
Murphy, William R.		Chief of Aerodynamics
Youth, Stanley		Head of Aero. Configuration Gp.

NAME	RANK	TITLE
LOCKHEED AIRCRAFT CORPORATION		
Cleveland, Frank A.		V. P. - Engineering
Smelt, Ronald		V. P. & Chief Scientist
Wilson, F. M., Jr.		Proj. Flt. Sciences Div. Mgr.
McDONNELL AIRCRAFT COMPANY		
Baldwin, Robert J.		V. P., Avionics Engineering
Barkey, Herman D.		V. P., Aircraft Eng.
Flesh, Edward M.		Director, Design Eng.
Miller, C. W.		Mgr. of Aerodynamics
Mongold, Clarence H.		Project. Aerodynamics Eng.
Parke, Darrel B.		Engineering Mgr.
NORTH AMERICAN ROCKWELL CORPORATION		
Blair, Morgan M.		Research & Eng. Staff
Johnston, E. W.		Director, Flight Technology
Ley, A. C.		Aerodynamics Supervisor
MacKay, J. K. L.		Technical Staff
Mark, Leon		Project Eng.
Marshall, P. L.		Mgr., Aircraft Development
McCarthy, John Francis, Jr.		V. P., Systems Eng.
Peterson, B. G.		Mgr., Tech. Support & Test Integration
Peticolas, R. P.		Program Mgr., Trainer Aircraft
Rose, Leonard M.		Mgr., Technical Eng.
Schweiger, M.		Mgr., R & D
Stone, G. M., Jr.		Mgr., Wind Tunnels
Swanson, W. E.		V. P., Eng. Aerospace Gp.
Willer, Jack E.		Eng. Project Mgr.

NAME	RANK	TITLE
NORTHROP CORPORATION		
Bratt, Robert W.		Mgr., Advanced Design
Brown, S. H.		Sr. Technical Specialist
Grogan, George C., Jr.		V. P., Product Development
Howe, E. Dabney		Mgr., R & D
Linder, D. W.		Mgr., Flt. Simulator Test Dept.
Weyl, C. J.		Mgr., Aerodynamics
VOUGHT AERONAUTICS DIV., LTV		
Clark, John Russell		Sr. V. P., Technical
Evans, T. M.		Sr. Engineer
Isely, F. D.		Sr. Engineering Scientist
Louthan, John D.		Flt. Technologies Mgr.
Prilliman, F. W.		Aero. Project Eng.
Stahl, Harold F.		Aero. Project Eng.
Upton, George T.		Dir., Engineering Technologies
USAF SCIENTIFIC ADVISORY BOARD, AEROSPACE VEHICLES PANEL		
Bogdenoff, Seymour M.		Prof. & Head, Gas Dynamics Lab, Dept. Aerospace & Mech. Sciences, Princeton University
Loewy, Robert G.		Dean, College of Eng. & Applied Sc., University of Rochester

APPENDIX B

QUESTIONNAIRE--COMPLETE SHORT FORM

FOR GOVERNMENT AND INDUSTRY

APPENDIX B

2 February 1971

To the Respondent:

This questionnaire represents a part of the attempt by the Air Force Systems Command to collect data which will permit an improvement in the aircraft development cycle. The primary thrust of this questionnaire is directed toward an improvement in the usefulness and effectiveness of the wind tunnels that are used in the development program.

You who were chosen to answer this questionnaire are experts in either systems development, flight testing, or facility testing. Many of you have experience in all three categories. All of you are recognized leaders in your profession, and your opinions and judgements will combine to provide valuable data and insight as problems are investigated and solutions pondered.

The questionnaire does not ask for compliments, complaints, or parochial views; instead, it seeks the truth as you see it. It is recognized that the testing program is only one of several variables that influence the success or failure of a particular aircraft development. Only you who have served in positions where you could weigh the influence of the many variables have the exclusive knowledge to contribute to this investigation.

Your anonymity will be preserved to the extent you desire. Unless you object, I plan to list all respondees by name and position as expert contributors to the study. I will not attribute any answer to you as an individual. I would like your name on the survey sheet for my own use in case I need to contact you for further clarification of some answers.

I realize that I am asking for some very difficult data. You may sometimes find it impossible to provide simple answers as requested. Please feel free to expand your answers on the back of the sheet or use additional sheets as needed. I thank you for your cooperation and effort.

JAMES G. MITCHELL

Date: ____________________

Personal Data

Name:

Title:

Grade or Rank:

Business Address:

Business Telephone:

Years Experience in:

Aircraft Development Programs: ___________ yrs.

Wind Tunnel Test Programs: ___________ yrs.

Flight Test Programs: ___________ yrs.

Questions 1 through 9 are directed toward an investigation of the conception and development of wind tunnel test programs. Seven statements are given in support of a hypothesis. It is expected that there will be some exceptions and qualifications to these statements, but you should indicate your general level of agreement or disagreement based upon your overall experiences and observations.

1. Emphasis on low development cost and short development time has the effect of encouraging the bidder to reduce the scope of his test program and thus increase risk.

Disagree Strongly ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ______.

2. There is a tendency to minimize attention to the development of the test plan because of the many other issues considered more important in the bid proposal.

Disagree Strongly ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ________.

3. The magnitude and quality of the test plan in the bid proposal has little influence on the evaluation of the bid and thus has little effect upon selection of the contractor.

Disagree Strongly ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ______.

4. The contractor does most of the work in preparing the test plan for systems development.

Disagree Strongly ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ______.

5. The military developing agency exerts very little influence on the magnitude or quality of the test plan.

Disagree Strongly ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ______.

6. Department of Defense test facility personnel exert very little influence on the magnitude or quality of the test plan.

Disagree Strongly ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ______.

7. NASA test personnel exert very little influence on the magnitude or quality of the test plan.

Disagree Strongly ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ______.

8. Do you believe that some reorientation of emphasis or procedure can improve the existing method of preparing and evaluating the test plan?

Yes ________ No ________.

9. If your answer to (8) is "yes," consider each of the possible courses of action noted below for its potential to provide an improved test plan and test program for systems development. Use the matrix to compare each suggested change. For example, in the first column you will compare alternatives (a) and (b), in the second column (a) and (c), etc. Place a (1) in the appropriate space to indicate your perference of the two courses of action being compared; place a (0) in the remaining space. If you consider the choices equal, put a (1) in both spaces. Fill all blanks.

a. Continue existing procedures, but have the military developing agency attach less importance to the test plan in the evaluation of the bid.

b. Continue existing procedures, but have the military developing agency attach more importance to the test plan in the evaluation of the bid.

c. Have the company bid the test plan only as a lump-sum expenditure and evolve the details if and when it gets the contract.

d. Omit the test plan from the bid proposal. Develop the test plan after contract award with the combined efforts of the selected contractor, Systems Project Office, and government test facility personnel. Add to the contract on a cost-plus-fixed-fee basis.

a.				X	X	X
b.		X	X			X
c.	X		X		X	
d.	X	X		X		

The Department of Defense has directed the Military Services to make some adjustments in the management of weapon systems acquisition. A part of this philosophy concerns a thorough flight evaluation of the aerospace system and its relation to tooling and production go-ahead. However, in this part of the survey the questions are directed toward the contributions to be made by the test facility prior to completion of the flight vehicle. The general thrust of the DoD directive is to invest development dollars to save production dollars; i.e., to find and correct mistakes and make appropriate trade-offs early in the development cycle where the penalty is not so high. Emphasis is on demonstration of performance and reduction of technical risk before commitment of funds for full-scale development. Questions 10 through 14 concern the role of the test facility as it relates to this policy.

10. Do you agree with the new policy and emphasis?

Strongly Disagree ____ Disagree ____ No Opinion ____ Agree ____ Agree Strongly ____.

Comment:

11. It is hypothesized that this shift in emphasis in the development cycle will permit the test facility to be more useful and influence the system development more strongly. Do you agree?

Strongly Disagree ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ______.

Comment:

12. The shift in emphasis in development will require:

__________ more facility testing.

__________ less facility testing.

__________ no change in facility test load.

13. Two important decision points arise in the development cycle prior to full-scale development. One decision point is at the end of the conceptual phase and one at the end of the validation phase. The decision to be made at each point is whether or not the program is ready to progress into the next phase. The two phases are briefly described below. In keeping with the philosophy of illustrating progress with hardware and performance demonstrations, please comment on the possible contribution of the test facility at these decision points. In other words, if you were the decision maker, what information would you like that could be derived from the test facility? Be as specific as possible and note any changes in timing you may prefer regarding when certain data are taken in the development cycle.

Conceptual Phase. This is the first phase in the development cycle and includes identification, definition and analysis of conceptual systems. Also included is experimentation and test of operational requirements, key components, critical subsystems and marginal technology. Major uncertainties are identified and a development program and preferred system are proposed.

Comment:

Validation Phase. This is the second phase and emphasizes hardware development and evaluation to resolve or minimize technical risks. The costs, schedules, performance and military needs defined in the conceptual phase are evaluated by the contractors who will do the full-scale development. The decision at the end of this phase may be either to cancel the development, proceed into full-scale development, or perhaps defer full-scale development until certain critical high-risk components are developed or technical problems resolved.

Comment:

14. It is considered poor management practice to place individuals or groups in a position where they may be required to make decisions against their own best interests. Because the possibility of program cancellation is an alternative at each decision point, some parties have more to lose than others and thus have an incentive to interpret the experimental data in such a way that the program will look good. It is not the intent of these statements to question anyone's honesty or integrity, but instead to orient the procedure in keeping with good management principles. Please comment on what you think would be a desirable procedure for analyzing and reporting on experimental data from the wind tunnel that is to be used in ascertaining compliance with expected performance. Include the roles of at least three parties in your comments; i.e., the contractor, Systems Project Office, and DoD test facility personnel.

Comment:

Most of the large aeronautical test facilities in the United States were built in the early 1950's. It is fact that these facilities often do not provide the test environment desired for development of advanced weapon systems. Questions 15 through 20 deal with this situation, its effects, and possible remedies.

15. Has the deficiency in environmental simulation in aeronautical test facilities had detrimental effects upon systems development?

None _____, Some _____, Much _____, Very Much _____.

Briefly comment on any specific examples you may know.

16. If test facility capability is not improved, what will be the effect on aeronautical systems development over the next decade? Performance limitations? More costly development programs? Briefly explain any consequences you may see.

17. There is a belief among some government and industry personnel that the government should provide the high cost-low use aeronautical test facilities for everyone's use, while industry should have its own backyard low cost-high use facilities. Do you agree with this general policy?

Strongly Disagree _____ Disagree _____ No Opinion _____ Agree _____ Agree Strongly _____.

Comment:

18. If you agree with the policy stated in Question 17, what do you think is a rule-of-thumb dividing line between the two types of facilities? Use dollars based upon today's construction costs. $ ________________.

If you think that some other measure than cost should be the dividing line, give your rationale.

If you do not agree with the general policy, please comment and give an alternative if you have one.

19. Do you believe that company-owned aeronautical test facilities help the company in obtaining government contracts?

None _____, Some _____, Much _____ Very Much _____.

Does this belief hold true even though the same capability is available for company use at a government test facility? Yes _____, No _____.

Comment:

20. You are probably aware that it may take 5 to 7 years to design, construct and bring to operational usefulness a large aeronautical test facility. Such a facility cannot contribute to the development of a weapon system if it is brought along in a parallel development program. Yet within the DoD, the present justification and funding system requires that the facility be closely tied to the test needs of an aircraft development program that carries a rather firm commitment. Please make any comments you have regarding this dilemma. How should procedures be changed? What do you believe is the soundest way to plan and fund large aeronautical test facilities to best meet test requirements and with least risk of building facilities which are not needed?

---

21. Do you believe that the DoD test facilities can better serve the aeronautical development programs by providing experienced personnel on-site to provide additional services; e.g., guidance on the test program, data analysis, recommendations, etc.? Yes _____ No _____.

Comment:

22. It is hypothesized that a very subtle change in aircraft design is being caused by the growing deficiencies in the test facilities. It is suggested that aircraft are sometimes designed to fit facility capability at the expense of optimum performance. It is suggested that compromise designs are accepted because facilities are not available to verify new ideas or theories with any degree of confidence. Such compromises in the aircraft are never attributed to facility deficiencies, for a conflict never arises between test requirements and facility capability.

Do you agree with the hypothesis:

Strongly Disagree ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ______.

Briefly note any examples from your experience or knowledge which support this hypothesis:

23. It is hypothesized that the aircraft development program could be improved and cost savings incurred if more effort were devoted to the wind tunnel test program earlier in the cycle, particularly prior to design-freeze on the first flight vehicle. Do you agree?

Strongly Disagree ______ Disagree ______ No Opinion ______ Agree ______ Agree Strongly ______.

Comment:

24. Many aircraft development programs experience further wind tunnel testing during the flight evaluation phase to investigate and correct deficiencies discovered during flight. Corrections and changes are more costly at this point than those made earlier in the cycle. Some of these deficiencies might have been prevented with a more thorough facility test program, but with attendant increases in cost and time of that phase

of the program. Briefly discuss--in a qualitative manner if necessary--your findings on the relative costs of more facility testing versus undiscovered design deficiencies, and express any ideas you may have to optimize this trade-off.

25. What have you found to be the major constraints that influence the quantity and quality of the wind tunnel test program in aircraft development (e.g., time, money, etc.)? If more than one, list in order of decreasing importance. Comment on specific development programs if you have such data.

26. When none of the test facilities can provide the desired simulation parameters, similar tests are sometimes performed in different facilities in an attempt to verify certain data. In your opinion, what part of the modern test program is motivated by such facility deficiencies? _______ per cent. Examples?

27. The functions which denote categories of use of the wind tunnel are as follows:

a. Verify the design hypotheses; i.e., assure that theory and past experiences have been applied correctly and produce expected results.

b. Generate new design information and improvements in the design concept; i.e., produce new technology to be applied to the system.

c. Expose difficulties which may have been overlooked; i.e., look for undefined and unexpected problems.

How do you rank the relative importance of these functions in the aircraft development program?

Most Important: ________________

Second: ________________

Third: ________________

If you do not think that these three functions adequately cover reasons for testing, please add others and rank.

Would you like a summary of the results of this survey? Yes _____ No ____.

APPENDIX C

QUESTIONNAIRE--LONG FORM FOR INDUSTRY

(First 25 Questions)

APPENDIX C

1 February 1971

To the Respondent:

This questionnaire represents a part of the attempt by the Air Force Systems Command to collect data which will permit an improvement in the aircraft development cycle. The primary thrust of this questionnaire is directed toward an improvement in the usefulness and effectiveness of the wind tunnels that are used in the development program. Some of the data requested can be obtained from historical documentation. Other data are not so objective, and are available only in your mind as you apply your experience and value system. The first 25 questions are directed toward an evaluation of a particular aircraft development program. The remainder should be answered on the basis of your total experience. The answers to the first 12 questions are essentially historical, and it is expected that all those who are evaluating the same aircraft will collaborate in obtaining this data. However, you are asked to provide independent answers to all those questions after number 12. I will discuss these answers with you and any others who may answer the questionnaire for this particular aircraft in a joint meeting at a later date. At that time we will try to resolve or explain any major differences of opinion.

The questionnaire does not ask for compliments, complaints, or parochial views; instead, it seeks the truth as you see it. It is recognized that the testing program is only one of several variables that influence the success or failure of a particular aircraft development, and only you who were on the scene can distinguish among these influences. You are urged to give thoughtful consideration to your answers for you hold exclusive knowledge through which performance of the testing program can be measured.

Your anonymity will be preserved to the extent you desire. Unless you object, I plan to list all the respondees by name, title, and company as expert contributors to the study. I will not attribute any answer to you as an individual. I would like your name on the survey sheet for my own use in case I need to contact you for further clarification of some answers.

I realize that I am asking for some very difficult data. You may sometimes find it impossible to provide simple answers as requested. Please feel free to expand your answers on the back of the sheet or use additional sheets as needed. I thank you for your cooperation and effort.

JAMES G. MITCHELL

Date: ____________________

Personal Data

Name:

Company:

Job Title or Position:

Business Address:

Business Telephone:

Years experience in:

Aircraft Development Programs: __________ yrs.

Wind Tunnel Test Programs: __________ yrs.

Flight Test Programs: __________ yrs.

Aircraft Development Program

1. Name of aircraft being evaluated:

2. Your position on this program:

3. Program began (contract signed): month ___________, year _________.

   Aircraft first flight: month ___________, year _________.

   Production go-ahead: month ___________, year _________.

   Program conclusion: month ___________, year _________.

The following questions are directed toward a breakdown of the wind tunnel test program into selected categories. You should include only the testing associated with the development program; i.e., exclude any retrofit or follow-on test programs which may have been performed after development unless these data are specifically requested. The "wind tunnel test program" is to include all aerodynamic or structural testing in wind tunnels which excludes development of the actual propulsion system. Propulsion - aircraft integration type tests are to be included.

4. At what date did the wind tunnel program make its last contribution to the first flight vehicle; i.e., when was design frozen on the first flight vehicle? month ________________, year ___________.

5. Wind tunnels are usually classified as subsonic, transonic, and supersonic with some overlap in capability. Please designate the total number of test hours in support of the development program in each type of facility and indicate the owner (or location) of the facility.

	Subsonic	Transonic	Supersonic
DOD	_________	_________	_________
NASA	_________	_________	_________
Own Facilities	_________	_________	_________
Other Industry Facilities	_________	_________	_________
Other (please specify)	_________	_________	_________
TOTALS:	_________	_________	_________

6. How many wind tunnels did you use on this program?

Subsonic _________, Transonic _________, Supersonic _________.

7. Designate the cumulative wind tunnel test hours that may be attributed to this program within the following restrictions:

Before contract award ___________________

At design-freeze on the first flight aircraft (ref. Question No. 4) ___________________

At the event of first flight ___________________

8. How many additional test hours have been collected in support of retrofit and follow-on development programs?

Subsonic ___________, Transonic ___________, Supersonic __________.

THE NEXT FOUR QUESTIONS ARE CONCERNED WITH WIND TUNNEL COSTS:

9. Wind tunnel costs are usually figured on an hourly basis and are primarily a function of the wind tunnel size and performance. Please note the amount of development testing accomplished in each category of price ranges. Base your estimates on today's costs. If you are not aware of the present facility charge rate, use the index at the end of this questionnaire to calculate a charge rate for Calendar Year 1971.

Under $800/hr: ____________ hrs.

$801 - $1500/hr: ____________ hrs.

$1501 - $3000/hr: ____________ hrs.

Over $3000/hr: ____________ hrs.

10. What was the cost of the wind tunnel test program in support of the system development? $ ______________.

11. How were these costs broken down?

Aerodynamic models $ ______________________.

Facility usage or operation $ ______________________.

Data collection and analysis $ ______________________.

Facility construction or modification which was special for this development $ ______________________.

Other (please specify) $ ______________________.

12. Were there other wind tunnel test costs that you did not pay and cannot estimate; e.g., operation of government facilities? Yes ______ No ________. Explain:

13. Compare this development program with others you have experienced. For those technical areas amenable to investigation in the wind tunnel, assess the level of technical difficulty (advancement of the state-of-the-art) at the time of development.

High ___________, Medium ___________, Low ___________.

Comment:

14. Were there constraints that influenced the quantity and quality of this wind tunnel test program (e.g., time, money, outside influence, etc.)? If more than one, list in order of decreasing importance. Explain:

15. Compare this development program with others you have known and rate its success. Was the development program successful in meeting technical objectives in a timely and economical manner? Ignore the ultimate usefulness or success of the system itself and evaluate only the development program.

Poor ______, Fair ______, Average ______, Good ______, Very Good ______.

16. In your opinion, how strongly did the wind tunnel test program contribute to the success or failure of the development program? Explain, and note other major contributing influences on this particular development program.

Very little ________, Moderately _________, Very much _________.

17. Did you experience difficulty in obtaining certain data on this program because of test facility deficiencies? Were certain simulation parameters inadequate? Explain:

18. When none of the facilities can provide the desired simulation parameters, similar tests are sometimes performed in different facilities in an attempt to verify certain data. Do you think some of your testing was motivated by such a facility deficiency? __________. If so, how much? ___________ per cent.

Please try to place yourself in time once again at the beginning of this development program, but give yourself benefit of the knowledge you have gained during and since this program. You have the opportunity to originate and implement a wind tunnel test program of your own choosing. You may change the magnitude of the program and shift emphasis within the program to provide what you believe to be the optimal. If you are enlarging the test program, use your own judgement of the value of additional data as compared with the additional time and cost of testing . Do not be limited by any original constraints which may have dictated the facility test program. You may need to exercise care in evaluating the usefulness of the test data where you were searching for verification of your design hypotheses. It would be easy in retrospect to eliminate any test program which only confirmed what you already thought. Please try to recall the uncertainty and risk which prevailed at that time. Questions 19 through 25 are concerned with your definition of the optimum facility test program for this particular system development.

19. In your opinion, the optimal wind tunnel test program would have been about ________ test hours and distributed as follows:

Subsonic __________ hrs.

Transonic __________ hrs.

Supersonic _________ hrs.

20. The optimal wind tunnel test program would provide most usefulness with the following distribution:

Before contract award ____________ hrs.

At design-freeze on the first flight aircraft (ref. Question No. 4) _____________ hrs.

At the event of first flight ____________ hrs.

21. The optimal wind tunnel test program would be distributed among facilities as follows:

Under $800/hr: __________________ hrs.

$801 - $1500/hr: __________________ hrs.

$1501 - $3000/hr: __________________ hrs.

Over $3000/hr: __________________ hrs.

22. What would be the approximate cost of your new optimal wind tunnel test program? $__________________.

23. Do you believe that implementation of your hypothetical test program would have resulted in:

Less overall development cost? Yes _____ No ______.

Superior system performance? Yes _____ No ______.

Shorter time to system demonstration? Yes _____ No ______.

Less flight testing required? Yes _____ No ______.

24. Were there deficiencies revealed in the flight evaluation of this aircraft that your optimal test program might have minimized or prevented (performance, control, structural, etc.)? __________. If so, explain.

25. The functions which denote categories of use of the wind tunnel are as follows:

a. Verify the design hypotheses; i.e., assure that theory and past experiences have been applied correctly and produce expected results.

b. Generate new design information and improvements in the design concept; i.e., produce new technology to be applied to the system.

c. Expose difficulties which may have been overlooked; i.e., look for undefined and unexpected problems.

In the aircraft development program being evaluated, what was the relative importance of the three categories? In your optimal program, what do you think should be more important? Rank the functions in decreasing order of importance.

	Past Program	Optimal Program
a.	____________	____________
b.	____________	____________
c.	____________	____________

If you do not think that these three functions adequately cover your reasons for testing, please add others and rank.

APPENDIX D

EXHIBITS OF COMMENTS BY RESPONDENTS

EXHIBIT 1

COMMENTS FROM THE QUESTIONNAIRES ON TEST FACILITY SUPPORT DURING THE CONCEPTUAL PHASE OF DEVELOPMENT

"Define the aerodynamic characteristics essential to predicting design mission performance, including take-off and landing high-lift preliminary performance. Provide inlet testing sufficient to establish the feasibility of attaining the required installed performance levels. Perform airloads tests of sufficient scope to enable making preliminary estimates of primary structure critical loads."

"Evaluate the contractor's technical concepts, approach to problem identification and solution, and probable success in the wind tunnel. In the flight simulator, evaluate the contractor's flight control configuration concept and ability to make trade-offs. Evaluate engine performance in a propulsion test call."

"The primary contribution of the test facility at this point is to furnish the data which allows the determination of what is possible to achieve in various technical areas of interest to the particular system. Examples would be materials data, aerodynamic efficiency, engine performance, sensor and display resolution--all of which might be expected to be available so that some indication of the expected system performance and probability of achieving this performance can be made. In general, the more data the higher the probability of success."

"The role of the wind tunnel must be in providing accurate parametric data on pertinent configurations to assure that the data used for comparative analyses are well founded."

"More analysis and preliminary design is accomplished at this time than any other. For a new configuration, introduction of new technologies and realistic estimates of the performance of a proposed system in a test facility is definitely required to obtain aerodynamic flow phenomena, aerodynamic loads, and to investigate sensitive areas. The data obtained can be used for trade-off studies, identifying uncertainties and providing numbers for describing sensitivity areas."

"Even this phase should be backed up by some hard test data. All too often the Air Force specifies a matrix of aircraft with various trades and

EXHIBIT 1--Continued

options. As a result, there usually is not a solid design in the bunch."

"Small-scale model tests of the airframe are needed to indicate aerodynamic parameters and other performance data expected. Stability data is needed to identify any problem areas. Control data could be needed in certain cases. All data should cover the Mach number range expected in the aircraft."

EXHIBIT 2

COMMENTS FROM THE QUESTIONNAIRES ON TEST FACILITY SUPPORT DURING THE VALIDATION PHASE OF DEVELOPMENT

"There should be extensive testing over the entire Mach number/angle-of-attack range on models which are heavily instrumented to obtain data for detailed flow diagnostics. There should be complete documentation of the steady-state and dynamic aerodynamic characteristics of the clean airplane and high lift configuration--including aeroelastic effects. Component loads and airloads distributions tests should be performed over the complete range of operating conditions to enable accurate definition of design loads for primary structure and a major portion of the secondary structure. If applicable, perform store-separation tests to assure compatibility of store-airframe combination."

"In a wind tunnel evaluate the contractor's aerodynamic configuration to assure that it is consistent with all design requirements (not just performance requirements). In a flight simulator evaluate flying qualities of the contractor's entry, considering failure cases, realibility, etc. In a propulsion test cell evaluate engine performance, effects of bleed, and nacelle environment (inlets and nozzle)."

"We need model tests at sufficiently large scale to tune flaps and controls, determine lift/drag at trim, and obtain realistic values of performance, stability and control. The test program must include dynamic stability tests if inertial characteristics indicate a questionable situation. The same is true for buffeting and aeroelastic problems. Engine performance should be determined in tests and sensitivity to engine attitude and flow distortion determined. Airframe-inlet integration problems might require special tests. In high speed aircraft, heat transfer tests in localized regions might be required."

"Test data on critical components will help to determine if the risks are in some way compatible with the expected benefits. Every possible risk cannot be eliminated."

"The decision-maker should be satisfied with large-scale data from test facilities. He should expect marginal technology to be reasonably well validated through accepted test techniques."

EXHIBIT 2--Continued

"The validation must be of a configuration(s) which can be practically developed into a piece of hardware."

"The role of the wind tunnel is to provide comprehensive and specific data on the selected configuration to assure soundness of design. Analyses of structural integrity, performance, flying qualities, etc. must be based on wind tunnel tests of models which simulate the proposed design as closely as possible."

"It must be certain that at least one base-line has been thoroughly tested and analyzed."

"All items must work properly in a validation test before going on to full-scale development. Since test conditions may be more realistic than in previous testing, some failure can be expected. When these occur, testing should be shifted to document problems and then stopped. When corrections are made, Validation Testing should continue or start over."

"At this point there should be hard test data on the final design. All too often, the contractor is still 'incrementing' and doesn't have final results."

"The answers from the test facility can be used to design the later flight tests."

EXHIBIT 3

COMMENTS FROM THE QUESTIONNAIRES ON MANAGEMENT OF TEST FACILITY VALIDATION DATA

"The SPO and DoD test personnel must develop test plan jointly. Test facility personnel make recommendations to SPO as a result of tests, but also send a copy to SPO's boss."

"Bring the contractor, SPO to best Federal facilities. The Federal Government is the buyer and accordingly must accept responsibility for quality and performance."

"Some day, aerodynamic performance data certified by a government laboratory will be required as presently done for engine performance data. The knowledge that certification will be done will aid an initial interpretation."

"When we reach a point in development where the SPO and DoD test facility personnel work as a team, the problem will be taken care of."

"Both the contractor and SPO are subject to these pressures. The test facility's role should be to assist the other two parties in solving problems. If test facility personnel became the judge of compliance, this role would be compromised since the other two parties would be tempted to hide problems. The best solution is an independent evaluation board within DoD."

"The SPO should lead a team of government experts in accessing facility data. Government test facility personnel should be instrumental on this team."

"Experimental data should be tracked by all participating parties on a continuing basis. Data review meetings can 'snow' even good and experienced people, and usually only one party's views are heard."

"The SPO should have overall responsibility, but the key to identifying and solving problems is communication between the SPO and test facility engineer. The procedures should not permit the test engineer to turn his data over to the SPO and forget it. The test engineer should participate in formulating the test program, conduct and report tests, and participate in interpreting tests with SPO. The contractor, working independently to

EXHIBIT 3--Continued

some extent, should end up with the same interpretation."

"The contractor would have prime responsibility for reduction, initial analysis and presentation of test data. These results should be collated, reviewed and analyzed by SPO, with significant technical assist from technical experts in discipline-oriented laboratories or organizations. Test facility personnel do not play a significant role!"

"I don't think any system will insure that the contractor or SPO will be objective in considering project cancellation, and I wouldn't waste time trying to design such a system. The job of the contractor and SPO is to make the project go and they should not be burdened in assessing whether to stop it. DoD test personnel can be more objective. NASA can be even more so and should be the source of an independent assessment on how the project is going. DAG type committees can be effective, but they need new faces and more time than usually used at present."

"Contractor, SPO and test facility personnel are 'involved' and are under pressure to keep the project going. We need outside review; i.e., significant expertise from outside DoD organization."

"DoD test facility personnel should be asked to verify the validity (or limitations) of data as applied to system performance estimation, including methods of data reduction and extrapolation to full scale. The contractor should provide the basic performance analysis. The SPO should make an independent check."

"Cold, hard facts derived from cold, impassionate, unbiased testing, reported formally to the SPO. No tampering with report by SPO; no arguing or modifying results as a consequence of developer problems. Neither contractors nor SPO's should grade their own papers. Not to say that test agencies should shower the world with test results. SPO acts as a customer to the test agency. The purchase he makes is unbiased testing--nothing less."

"I strongly support the need for objectivity which I believe cannot be rendered by either the contractor or SPO, both of whom will and should lean in favor of the program. DoD test facility personnel should maintain a capability to analyze and report on experimental data independent of the SPO and contractor."

EXHIBIT 3--Continued

"DoD test facility personnel should present the test data and analyze, if possible. The contractor should present his reaction to the data as presented--explaining major points of difference, if any. The SPD should state program impact and make objective recommendation to the Commander AFSC and Chief of Staff."

"Since both the contractor and the SPO have vested interest in keeping the program going, a separate report by independent test agencies should provide top management with their results and analyses of both model and full scale testing."

"This is a key point--one that is now missing in our system. In our older practice, when I got my back up in the laboratory over a technical point, the SPO had difficulty in overriding. This checks and balances system is absent now. The contractor wants to sell and hope for the best--so does the SPO--and then perhaps trouble."

"The primary role at major decision points should lie with the contractor and SPO, supported by their respective technical groups. The AFSC Laboratories should be deeply involved in technical evaluation of the data. DoD test facility personnel should play a minor part--primarily in interpreting test procedures that may come under question."

"When it comes to evaluating the contractual compliance with predicted performance, matrix management might be applied effectively by the SPO. The contractor and the SPO, backed by technical specialists from DoD Laboratories and Test Centers, would agree beforehand on the parameters to be measured and acceptable deviations based on the experimental errors and past ground/flight test correlations. The calibrations of the facility and model instrumentation, as well as ground vs. flight similitude, would be essential factors to the specialists in the data evaluation. The SPO has the responsibility for decisions; however, he could do with better advice in the decision making process."

"Laboratory/test facility personnel should carry equal weight in judging performance of a vehicle as do the contractor and SPO. Independent evaluation reports are needed--not just test reports."

"There have been indications that the SPO and Contractor will look at the optimistic side of a set of data. This is a normal situation and unbiased engineers ought to be consulted. A procedure that should be acceptable

EXHIBIT 3--Continued

is to have DoD test facility personnel analyze and report the data. The solution to this problem is not always clear. However, in most instances DoD test facility personnel have the benefit of other programs and test data that is not familiar to the contractor or SPO. In this, the interpretation of the data is the major issue."

"Both contractor and SPO must analyze the data in context with other data in order to independently assess the probable performance. Test facility personnel are rarely, if ever, in a position to associate isolated test results with a total performance estimate. Often the model is not of the latest configuration and they are not really knowledgeable of the performance trade-offs that may be acceptable to the SPO."

"The engineering offices in our major SPO's are now quite capable of making independent analyses of the more significant wind tunnel data to check on the contractor's conclusions. This type of in-house capability should be continually improved enlisting the help of technical specialists from the facilities. In particular, test facility engineers should provide all the knowledge required to interpret the test data, provide wind tunnel and balance corrections, judge the accuracy of the final results, and determine whether additional testing is required."

"Require the SPO to have two separate evaluations of significant go-no go events; i.e., one inhouse SPO and another by a group of external experts. The SPO should be required to present the results of the outside experts along with his established position."

"The configuration evaluated will not be the one put into production; therefore, attaching too much significance to the wind tunnel data during the evaluation is not proper. As far as evaluating the data, all government personnel who have the necessary skills should participate."

"I would recommend test facility validation of tests and evaluation/interpretation by an agency independent of, or at least in parallel with the SPO and contractor."

"The SPO should place more weight on the advice of the Air Force engineering community--less on contractor's opinion."

"Data should be obtained at DoD or NASA facility by personnel capable of analyzing the results. Competitors should test in the same facility at

EXHIBIT 3--Continued

approximately the same time period. Each contractor should report the results as he sees them. DoD and/or NASA personnel, in conjunction with the SPO, should compare the contractor's results."

"The test facility people are there to perform tests as the contractor and/or SPO may decide. The facility people are not deciders of anything--except how to run the tests competently and expeditiously, and to report exactly and completely what they did and what they found--also what, in view of their experiences, the tests mean."

"Of all the parties involved in the interpretations of wind tunnel data, the contractor has most to lose if the data is not correctly representative of the final product. He should therefore have the sole responsibility for analysis and application of the wind tunnel data. The DoD test facility personnel should assume the role of expert advisers on test facilities practices."

"Both DoD test facility personnel and contractor provide assessment of data to the SPO. He will then have a range of values--conservative to optimistic--upon which he can base his decisions."

"Since a degree of subjectivity is assumed, it is important to establish a procedure by which proper checks and balances are created, while assuring that the program does not become bogged down in interpretation type arguments. It is proposed that a dual semi-independent role be adopted by the contractor and DoD test facility. The contractor will submit analysis and reports (used in establishing compliance) for review (not approval) by the DoD facility. Both parties thereafter submit their conclusions and/or differences to the SPO as final arbitrator."

APPENDIX E

REGRESSION PROGRAM

APPENDIX E

REGRESSION PROGRAM

Statistical Approach

The aircraft used in this study must be considered "random samples" for statistical analysis. A random sample must meet the criteria that it be selected from a universe where every member has an equal chance of being drawn; further, any method that associates the selection of an item with the classification of the item being selected must be avoided. As noted in the text of Chapter VI of this report, selection criteria and constraints remove some of the randomness from the data; however, because the sample is such a large portion of the universe, this is not expected to influence the results.

The dependent variable (optimal test hours at first flight) is almost always affected by many variables, some of which cannot (or the effects cannot) be reasonably quantified; they may sometimes be too numerous to consider. The purpose in this regression is to pick out a few important influencing variables that can be identified early in an aircraft development cycle. These variables are studied for their possible aid in illuminating the dependent variable. Any good book on statistics or quality control will provide details on the multiple regression analysis and the tests of the results (23 and 24). The computer program used in this analysis is available at the Vanderbilt Computer Center (25).

The multiple correlation coefficient (R) measures the degree of association between the dependent variable and the function of the independent variables as represented by the regression equation. Let the regression equation be represented by:

$$Y_c = F\ (X_1,\ X_2,\ X_3\ --\ X_k)$$

where:

Y_c = test hours calculated from regression equation

X = independent variable (e.g., thrust, weight, etc.)

k = number of independent variables in the regression

Other definitions which will be needed are:

Y = dependent variable measured value from aircraft program

$\bar{Y}$ = mean value $= \frac{1}{n} \sum_{i=1}^{n} Y_i$

n = number of individual data points (aircraft).

$$S_c = \left(\frac{1}{n} \sum_{i=1}^{n} (Y_i - Y_{i_c})^2 \right)^{1/2}$$

S_c is the standard error of estimate of Y, and is the variance of the deviations from the universe plane of regression.

The multiple correlation coefficient is then defined as

$$R = (1 - S_c^2 / S^2)^{1/2}$$

where:

$$S = \frac{1}{n} \sum_{i=1}^{n} (Y_i - \overline{Y_i})^2$$

The ratio S_c^2 / S^2 is the percentage of the variance of Y that is unexplained by the regression equation; therefore, R^2 measures the percentage of explained variance.

Multiple regression equations usually provide more precise estimates than simple regression equations. However, on occasion the addition of a variable does not reduce the residual sum of squares suffic-

iently to offset the loss of a degree of freedom. It is sometimes desirable to determine if the addition of variables significantly improves the ability of the regression equation to predict the dependent variable, or if the indicated improvement is due to "chance." Also, one would like to be able to compare the significance of two regression equations with different numbers of independent variables. If it is assumed that both universes are normal and the samples are independent, this can be determined from an F distribution. Let the two universes be designated by subscripts a and b. It is hypothesized that the two variances are equal: i.e., $S_a = S_b$. The F distribution is the sampling distribution of the statistic $\hat{S}_a^2 \; S_b \; / \; \hat{S}_b^2 \; S_a^2$, where $\hat{S}^2 = nS^2 \; / \; n - k$. The percentage points for the F distribution are available in tabular form. From calculation of the F-ratio and knowledge of the degrees of freedom, one can find the probability (P) that an F as large or larger than the one obtained would occur by chance; i.e., the probability that the hypothesis would be accepted by chance. For most cases, the hypothesis is rejected if the probability is greater than about 0.05.

Summation of Selected Data

Table 32 contains the multiple correlation coefficients for the case of 33 aircraft (all except the X-15 and XC-142) for the various predictors and mathematical formulations. It is observed that the combination of raw predictors and raw optimal hours gives the best multiple correlation coefficient for every group of predictors. Weight and thrust gave the highest F-ratio (80.4); all of the predictors are within acceptable probability limits. Comparison of predictors weight, thrust, speed, and year, both with and without categories, gives an F-ratio = 0.809 and P = 0.503. Comparison of predictors weight, thrust and speed, both

TABLE 32

MULTIPLE CORRELATION COEFFICIENTS FOR 33 AIRCRAFT

Predictors	Correlation Coefficient (R)			
	Case 1	Case 2	Case 3	Case 4
Weight, thrust, speed, year, 3 categories	.927			
Weight, thrust, speed, year	.919			
Weight, speed, year	.801			
Thrust, year	.781			
Year	.506			
Weight, thrust, speed	.918	.681	.744	.734
Weight, thrust	.918	.673	.741	.694
Weight, speed	.755	.638	.670	.700
Thrust, speed	.843	.662	.701	.726
Weight	.525	.448	.448	.432
Thrust	.776	.575	.600	.609
Speed	.610	.530	.573	.604

Note:
Case 1: Raw Optimal Test Hours from Raw Predictors
Case 2: Raw Optimal Test Hours from Log Predictors
Case 3: Log Optimal Test Hours from Log Predictors
Case 4: Log Optimal Test Hours from Raw Predictors

with and without year, gives an F-ratio = 0.249 and P = 0.627. Both categories and calendar year were omitted as predictors after the initial computer runs because their contribution to the prediction equations was not significant. Speed could have been dropped for the same reason, but was retained at the author's option. Because of the dominance of the SST data over the statistical analyses, none of these regressions is presented and these data will be explained no further.

The case for 20 aircraft is presented in Table 33. The ratio of thrust-to-weight as a predictor was also tested, but the results were not significant and are not presented in the Table. The addition of the ratio to the predictors weight, thrust and speed gave an F-ratio = 0.078, P = 0.783. The case of raw optimal test hours from raw predictors again gave the better multiple correlation coefficients, as demonstrated in Table 33. The F-ratios and probabilities of the regression equations for this case are shown in Table 34.

TABLE 34

F-RATIO AND PROBABILITY FOR REGRESSION EQUATIONS

Model	Predictors	F-Ratio	Probability
1	weight, thrust, speed, year	10.30	0.0005
2	weight, thrust, speed	14.64	0.0002
3	weight, thrust	22.64	0.0001
4	weight, speed	16.15	0.0003
5	thrust, speed	20.02	0.0001
6	weight	8.93	0.0078
7	thrust	20.84	0.0004
8	speed	6.57	0.0186

Again, calendar year of first flight did not add significantly as a predictor. A comparison of Models 1 and 2 from Table 34 gives an F-ratio = 0.004, P = 0.999. Also, speed did not contribute much to thrust and weight as predictors; comparison of Models 2 and 3 gives an F-ratio =

TABLE 33

MULTIPLE CORRELATION COEFFICIENTS FOR 20 AIRCRAFT

Predictors	Correlation Coefficient (R) Case 1	Case 2	Case 3	Case 4
Weight, thrust, speed, year	.856	.778	.686	.735
Weight, thrust, speed	.856	.742	.670	.735
Weight, thrust	.853	.656	.572	.705
Weight, speed	.809	.741	.666	.729
Thrust, speed	.838	.728	.652	.735
Weight	.576	.518	.440	.506
Thrust	.733	.610	.525	.626
Speed	.517	.437	.421	.479

Note: Case 1: Raw Optimal Test Hours from Raw Predictors

Case 2: Raw Optimal Test Hours from Log Predictors

Case 3: Log Optimal Test Hours from Log Predictors

Case 4: Log Optimal Test Hours from Raw Predictors

0.356, P = 0.565. Seemingly, weight and thrust should be the best predictors (Model 3). However, it is noted (26) that in the universe itself, the standard error of estimate of a multiple regression is usually less than, or at the most, equal to, the standard errors of estimate of regressions of lower order. In the universe, it is usally possible to make more precise estimates from a multiple regression equation than from regressions of lower order. A further concern is the distribution of the residuals, the magnitude of the constant, and the ability of the regression equation to predict outside its range of data. The author has already stated his preference for Model 2 (thrust, weight, and speed). Since the purpose of these regressions is to permit an estimate of optimal test hours from limited knowledge of the aircraft, all the predicting equations are given so that some estimate can be made with whatever information is available.

Model 1:

$H = 3530 + 0.124\ T + 0.877\ S - 0.0194\ W - 21.5\ Y$

Model 2:

$H = 2100 + 0.118\ T + 1.171\ S - 0.0181\ W$

Model 3:

$H = 2932 + 0.143\ T - 0.0241\ W$

Model 4:

$H = -235 + 0.0099\ W + 4.952\ S$

Model 5:

$H = 524 + 0.0437\ T + 3.572\ S$

Model 6:

$H = 4392 + 0.0092\ W$

Model 7:

$H = 3524 + 0.0479\ T$

Model 8:

$H = 2065 + 4.488\ S$

where:

H = optimal test hours at first flight.

T = total maximum sea-level-static thrust for the aircraft, with afterburner, if installed (pounds).

W = aircraft gross takeoff weight (pounds).

S = maximum speed at best altitude in miles per hour

Y = calendar year of first flight (use only last two digits).

GLOSSARY

This glossary is intended to provide identification and quick reference for abbreviations and terminology used in this report which may be unfamiliar to some readers.

AEDC: The Arnold Engineering Development Center is an Air Force test center; located there are wind tunnels, engine test cells, and other environmental simulation equipment which is designed to perform testing on aerospace systems and components.

AFSC: The Air Force Systems Command is the Air Force organization which has the responsibility for advancing aerospace technology and producing new and better aerospace weapon systems. AEDC and ASD are parts of this organization, whose headquarters is at Andrews Air Force Base.

ASD: The Aeronautical Systems Division is a part of the Air Force Systems Command and is located at Wright-Patterson Air Force Base, Ohio. ASD contains the Systems Project Offices and expertise to direct contractors in the development of aeronautical systems.

Backyard Test Facilities: These are test facilities (e.g., wind tunnels) which are located at a contractor's plant. Their construction may be funded either by the contractor or by the government in support of development of some system. They are usually relatively small when compared to AEDC and NASA test facilities.

DoD: The Department of Defense is at the summit of a command echelon which includes (in order) DoD, USAF, AFSC, and AEDC.

Facility Test Plan: This is a detailed set of specifications which designates quantity of testing, types of tests, models, and test facilities which will support development of a given aerospace system. The test plan is usually prepared by a potential contractor as a part of his proposal.

Flight Prototypes:

Pre-production (but full-sized) aircraft which fly under their own power. Competitive flight prototypes result when more than one contractor builds flight prototypes for competition via flight demonstrations.

Model Fly-Offs:

Scaled-down aerodynamic models of more than one contractor's proposed final design are subjected to competitive evaluation in wind tunnels.

NASA: The National Aeronautics and Space Administration possesses a number of substantial aeronautical test facilities to support its mission of aerospace research and technology advancement. The aeronautical test facilities are primarily located at the Langley, Ames and Lewis Research Centers.

Paper Studies:

Analyses which are used as evidence to support a contractor's claim for potential system's performance; in contrast to demonstration of performance with hardware, models, components, etc.

Service Funding:

Sometimes called industrial funding. The service funded activity (AEDC test facilities) operates with a working capital fund, from which operating expenses are paid, and which is reimbursed through charges to organizations which use the services (e.g., ASD and military contractors). This contrasts with a previous funding system whereby AEDC received an annual operating fund and provided testing at no charge to Air Force users.

SPD: The System Project Director is a high ranking Air Force Officer who directs the SPO.

SPO: The System Project Office is established within the AFSC to develop a particular weapon system. The SPO's for aeronautical systems are located within ASD.

USAF: The United States Air Force Headquarters is located within the Pentagon. AFSC develops aerospace systems in consonance with USAF plans and directions.

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13. ABSTRACT

Some of the major problems associated with the use and usefulness of aeronautical test facilities (wind tunnels, etc.) in the development of aerospace systems are defined and analyzed. Contributions to the study have come from 117 of this country's more experienced and prominent aerospace experts from government and industry. The origin of the facility test plan and the use of the test facility to support DoD system's development philosophy are explored and suggestions are made to reduce conflicting incentives and permit an expanded role for the test facility. The deficiencies in test facilities are shown to produce consequences which are resulting in higher system cost and less system performance. The major facility inadequacies are enumerated and specific examples are noted wherein lack of test capability has had detrimental effects on system performance.

Thirty-five of the recent aircraft development programs are studied and evaluated to determine a procedure whereby the use of the test facility can be optimized. A multiple regression analysis is used to develop a procedure for defining an optimal facility test program. The procedure is expected to be useful to those who must develop or evaluate facility test plans and to those who must predict test facility future work loads. An estimating procedure for predicting testing costs is also suggested.

Several procedural and Air Force policy changes are recommended.

14. KEY WORDS	LINK A		LINK B		LINK C	
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